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**Proceedings of Special Symposium:
The Biology of Marine Wastewater
Outfalls in Southern California
Sponsored by
The Southern California
Academy of Sciences
June 5, 1993**

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Preface

For its annual meeting the Southern California Academy of Sciences frequently sponsors a session emphasizing an environmental issue. We were approached by the Academy to identify a regionally important environmental issue and to arrange a symposium on that topic. California's 1,000 mile plus coastline and our interests and experience with it, made this an easy choice. Accordingly, we identified the biology of marine wastewater outfalls in southern California as the topic of the symposium.

Once the topic was set we searched for a central theme for the symposium, i.e., secondary production and ocean outfalls, trophic transfer and wastewater disposal, etc., which would provide guidelines for inviting speakers. After some discussion, we abandoned developing a central theme. Rather we opted to exploit the wealth of experience of seasoned practitioners, actively pursuing environmental studies in southern California's coastal waters, leaving the important area of policy management for another time and venue. With this decision, we encouraged scientists to develop papers along lines of their own choosing. We believe this self interest approach engenders an enthusiasm and commitment stronger than receiving an arbitrary assignment of our choice. The schedule of presentations is included in the appendix. Eight presentations were made. One speaker declined to contribute a paper to this proceedings and another presentation was committed to a publication elsewhere. We wish to thank Dr. Mary Bergen, Southern California Coastal water Research Project (SCCWRP) for presenting a paper for SCCWRP, while the senior author of the paper was in transit between positions. One paper not presented at the symposium was added because of its relevance and because we wished to posthumously honor a colleague formerly active among marine pollution scientists.

As the proceedings will show, several authors reported on soft-bottom benthos, one reported on 20 years of monitoring dealing with kelp, finfish, epibenthic invertebrates and soft-bottom benthos, while others presented papers on sediment bioassays, histopathology of demersal fish, and the impacts of wastewater bacteria

on shellfish. It is our firm conviction that the credibility of the symposium, and hence the proceedings benefited from emphasizing scientists actively working on these coastal problems.

We are most grateful to the scientists who participated in the symposium without whose efforts this proceedings would have been possible. Moreover, the proceedings would not have been published without the financial support of the County Sanitation Districts of Orange County, California. At this time, it is our pleasure to acknowledge members of the Districts' staff, Mrs. Anna Ubaldini and Mrs. Marian Moore, who handled the correspondence for the symposium, and who played a major role in processing the manuscripts for the proceedings. We wish to thank Dr. David Soltz, Chairman of the Biology Department at the California State University Long Beach, who invited us to present the symposium, and who coordinated meeting arrangements on the Long Beach campus June 4-5, 1993. Finally the efforts of Mrs. Margaret Barber, Southern California Academy of Sciences, and Dr. Daniel Guthrie, Claremont McKenna College, have greatly facilitated publication of the proceedings.

Don Maurer
Irwin Haydock
September 1994

Introduction

The amenities (Mediterranean climate, mountains, ocean) of southern California, have conspired against this region by attracting almost 15 million people to the six county area. Ranching and agriculture dominated earlier times gradually yielding to oil exploitation, light to heavy industry and tourism. Moreover, many of these people gravitated to the coastal zone. Assuming that human activities rather than natural processes produce pollution, the mass of people ensconced in the coastal zone places great stress on the amenities cited above. A clear case of killing the goose that lays the golden egg.

With expanding regional population growth the oldest form of pollution (domestic waste) has assumed enormous proportions. Response to this problem by engineers and scientists has seen the development of four major sanitation districts (City of San Diego, Orange County, Los Angeles County, City of Los Angeles) and several smaller ones which operate ocean outfalls. The latter represent known point sources of pollution to the ocean. In addition to these point sources, activities of this growing population have also expanded opportunities for, and increased the area for multiple nonpoint sources of pollution to the ocean. If the former requires improved wastewater treatment, then the latter requires adoption of regional practices to reduce input of contaminations coupled with watershed management.

Both regional and national officials recognized this growing problem and so in 1972 the U.S. Congress enacted the Clean Water Act (CWA). The CWA required publicly owned treatment works (POTWs) to provide secondary treatment to their

discharged effluent. This act also carried with it a considerable expenditure of public monies (billions of dollars). From 1972 to 1977 questions arose concerning the validity and economic feasibility of applying an all inclusive technological solution without examining warranted exceptions. Because of strong entreaty by managers and environmental scientists Congress was persuaded to amend the CWA in 1977. The amendment (Section 301(h)) authorized the U.S. Environmental Protection Agency (EPA) to grant variances (waivers) from full secondary treatment for POTWs that discharged into deep, well-mixed marine waters; administered a rigorous industrial waste source control program; and demonstrated protection of public health and the environment. Section 301(h) represents Congress' recognition that, under certain carefully prescribed circumstances, such discharges do no harm and there is no reason for the public to assume the significant monetary costs of secondary treatment with its associated air and land environmental impacts.

Notwithstanding, the potential relief of significant monetary costs, Section 301(h) confers a serious responsibility on dischargers. The responsibility entails extensive documentation (monitoring program) to demonstrate that the effects of the ocean outfall are ecologically insignificant and essentially restricted to the Zone of Initial Dilution (ZID). It deserves mentioning now that even those Districts not pursuing a waiver are also required by law to monitor the impact of their outfall. Since southern California has four of the larger ocean outfalls in the world, this level of wastewater disposal has produced a great deal of monitoring activity. The results of this activity are reported in annual reports, ultimately destined for enforcement agencies and are also occasionally published in regional and national journals. However, the level of dissemination of results to a broader audience is not commensurate with the level of monitoring activity. This proceedings represents a modest attempt to stimulate efforts to report on these studies and a concentrated effort to focus on environmental impacts associated with ocean outfalls in southern California's coastal waters, as seen through the eyes of practicing scientists.

For the billions of dollars spent nationally and regionally for full secondary treatment, what is the public getting in terms of environmental quality for all this money? To start with, millions of dollars are annually being spent through monitoring programs to answer this question in southern California. This proceedings provides some modicum of information to address this question. Without anticipating too much the presentations herein some marked changes in environmental quality in and around outfalls in southern California's coastal waters have occurred with treatment ranging from advanced primary and partial secondary (50:50) to full secondary treatment. These trends are certainly encouraging. However, as emissions from point sources (ocean outfalls) decline, contributions of contaminants from nonpoint sources increase. One is left with the uneasy feeling that even if these outfalls were terminated immediately (which is certainly not feasible for a variety of reasons) that multiple nonpoint sources and extensive water diversion projects would continue to stress the coastal zone. This does not obviate the need to commit to upstream reclamation, stringent source control and improved treatment practices, but it does bring into question whether public monies destined for universal application of secondary treatment will effectively resolve these problems. Rather the answer or the more appropriate application of mon-

etary resources should be applied to multiple nonpoint sources and watershed management to reinvigorate regional and national coastal waters. These larger issues are not the central theme of this proceedings, but they are briefly assessed herein.

Infaunal Patterns in the Vicinity of a Small Coastal Wastewater Outfall and the Lack of Infaunal Community Response to Secondary Treatment

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Abstract.—In July 1985 the Encina Wastewater Authority began discharging advanced primary treated wastewater into Southern California coastal waters at a depth of 45 meters. This discharge was upgraded to full secondary treatment in October 1988, which resulted in substantial improvements in effluent quality. An eight year monitoring program has recorded the response of the infaunal community to the wastewater discharge and changes in treatment. Except for lower abundance of *Amphiodia urtica* near the outfall, the wastewater discharge appears to be beneficial to the infaunal community by enhancing diversity. There were no indications of temporal changes related to improved treatment levels.

The environmental impacts associated with coastal wastewater discharges depend upon numerous factors, including the level of treatment, volume of discharge, types and concentrations of contaminants, outfall design, and the receiving water environment. Current wastewater management policies are rooted in the 1972 amendment to the Federal Water Pollution Control Act, which in 1977 was reauthorized and amended as the Clean Water Act. The technology-based standards for wastewater discharges were established in 1973 based upon achievable secondary treatment performance standards and require a minimum 85% removal and 30 mg/L effluent concentration limit for both five-day biochemical oxygen demand and total suspended solids (TSS) (NRC 1993).

Much controversy and debate have focused on whether full secondary treatment performance is the most cost-effective method for controlling wastewater discharge impacts to coastal ecosystems. Because ocean currents disperse wastewater discharges readily and dissolved oxygen depletion is rarely a problem in open coastal marine environments, ocean dischargers have argued that they should be exempted from the costs of implementing full secondary treatment. The 1977 Clean Water Act recognized the merits of these arguments and provided a waiver process, although the time to apply for a waiver expired in 1982. Due to these and other past legal and political decisions and to the large costs associated with reaching secondary treatment standards, several large marine dischargers continue to take issue with the law. They continue to question the benefits of full secondary treatment for improving environmental quality and raise new issues related to the management of the coastal environment and water quality (NRC 1993).

The Encina Wastewater Authority (EWA), which operates and maintains a treatment facility in Carlsbad, California, discharges approximately 20 million gallons per day of effluent through an ocean outfall. The outfall pipe and diffuser extend 2,400 m offshore, with the diffuser section at an average water depth of

45 m. Between July 1985 and October 1988, this facility discharged advanced primary treated wastewater (APT) by blending 47% primary treated wastewater and 53% secondary treated wastewater. This discharge was upgraded to full secondary standards in October 1988, and secondary treatment levels have continued until the present time. Since July 1985 a marine monitoring program has consistently sampled and monitored the receiving water environment and provides an opportunity to assess the environmental impacts associated with the discharge and changes related to the two treatment levels. This paper focuses upon the infaunal community and its response to the wastewater discharge during this period of change in treatment levels.

Methods

Effluent parameters including temperature, biochemical oxygen demand (BOD), and total suspended solids (TSS) were measured daily (except in 1986–87, when measurements for BOD and TSS were measured monthly), oil and grease was sampled twice a week, and measurements for dissolved oxygen (DO) and ammonia (as nitrogen) were taken weekly. Concentrations of metals and pesticides were measured monthly.

For receiving water samples, five nearshore stations, N2A, N3, N4, K1, and K2, were located 1,564 to 1,903 m from the midpoint of the discharge diffuser at depths ranging from 9 to 15 m (Figure 1). Six offshore sampling locations were located along the 45 m isobath at three distances down and upcoast from the diffuser (Figure 1). Stations Z1 and Z2 represented the ZID (zone of initial dilution) boundary stations, which were located 45 m down and upcoast from the diffuser, respectively. Two gradient stations, G1 and G2, were located 260 m down and upcoast from the diffuser, and reference stations R1 and R2 were located 3,623 m and 4,126 m down and upcoast, respectively.

The Carlsbad Submarine Canyon, located near the center of the study area, denotes a transition zone in continental shelf morphology with differences in bathymetry, shelf slope, shoreface, and sediment sizes found to the north compared to the south (USACE-LAD 1990). Average sediment sizes south of Carlsbad Canyon are almost twice that of the finer sediments to the north (MEC 1992). Thus, sediment grain sizes are much finer at the upcoast reference Station R2 compared to the other five stations, which are located south of the Canyon. Station G2 appears to represent a gradient in grain size between reference Station R2 and stations downcoast (MEC 1992).

Receiving water quality measurements were made monthly at the five nearshore and six offshore stations. From 1985 to June 1989, parameters were measured from discrete samples collected at 3 m intervals through the water column. Beginning in July 1989, a Seabird SBE-25 water quality analyzer was used for in situ measurements of water temperature, pH, DO, salinity, and depth. Light transmittance data were collected in situ using a Seatech profiling transmissometer with a 0.25-m path length. After each profile was taken, discrete water samples were collected at surface, midwater, and bottom depths using Van Dorn water bottles. These samples were used for oil and grease and TSS analyses.

Sediment parameters and contaminant levels were measured annually in August or September at the six offshore sampling locations. Sediment measurements consisted of total organic carbon (TOC), particle size, dissolved sulfides, BOD,

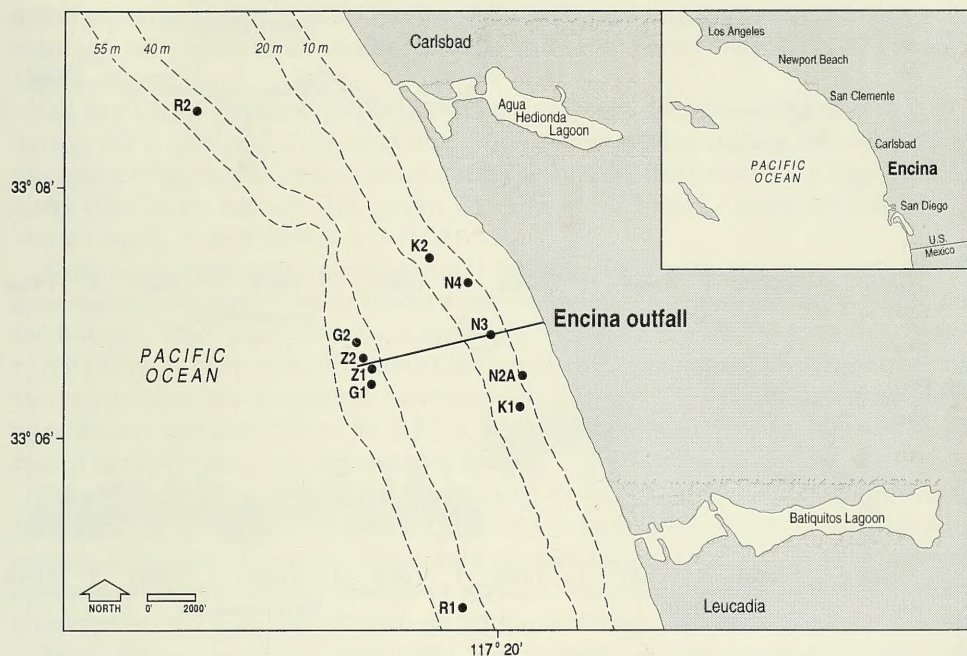


Fig. 1. Encina outfall and sampling stations.

oil and grease, and priority pollutants (metals, cyanide, volatile organic and extractable organic compounds).

Infaunal samples were collected at the six offshore stations in August or September and in February or March of each year (except 1987, when samples were collected in May). At each station, five replicate infaunal samples were collected using a modified 0.1 m² Van Veen, and collected sediments were screened through a 1.0 mm sieve.

Results

Effluent quality during the periods of APT and full secondary treatment is described. Temporal patterns for sediment contaminants and infaunal community parameters are evaluated for outfall effects and for changes that correspond to the shift to full secondary treatment.

Effluent monitoring. — Dissolved oxygen values are shown graphically in Figure 2A. DO concentrations showed a regular seasonal cycle, with the highest values occurring in the winter and the lowest values in summer. Changes in the effluent DO concentrations were negatively correlated with temperature, suggesting that temperature was the driving force for the seasonal variation.

Dissolved oxygen values showed an abrupt, long-term increase, which began with the shift to full secondary treatment in October 1988 (Figure 2A). The vertical line in the figure marks the approximate starting date for secondary treatment. The horizontal lines are regression lines for data collected during APT and secondary treatment periods. The slope of the line for APT was not significantly different from zero, indicating no trend over time during this treatment period.

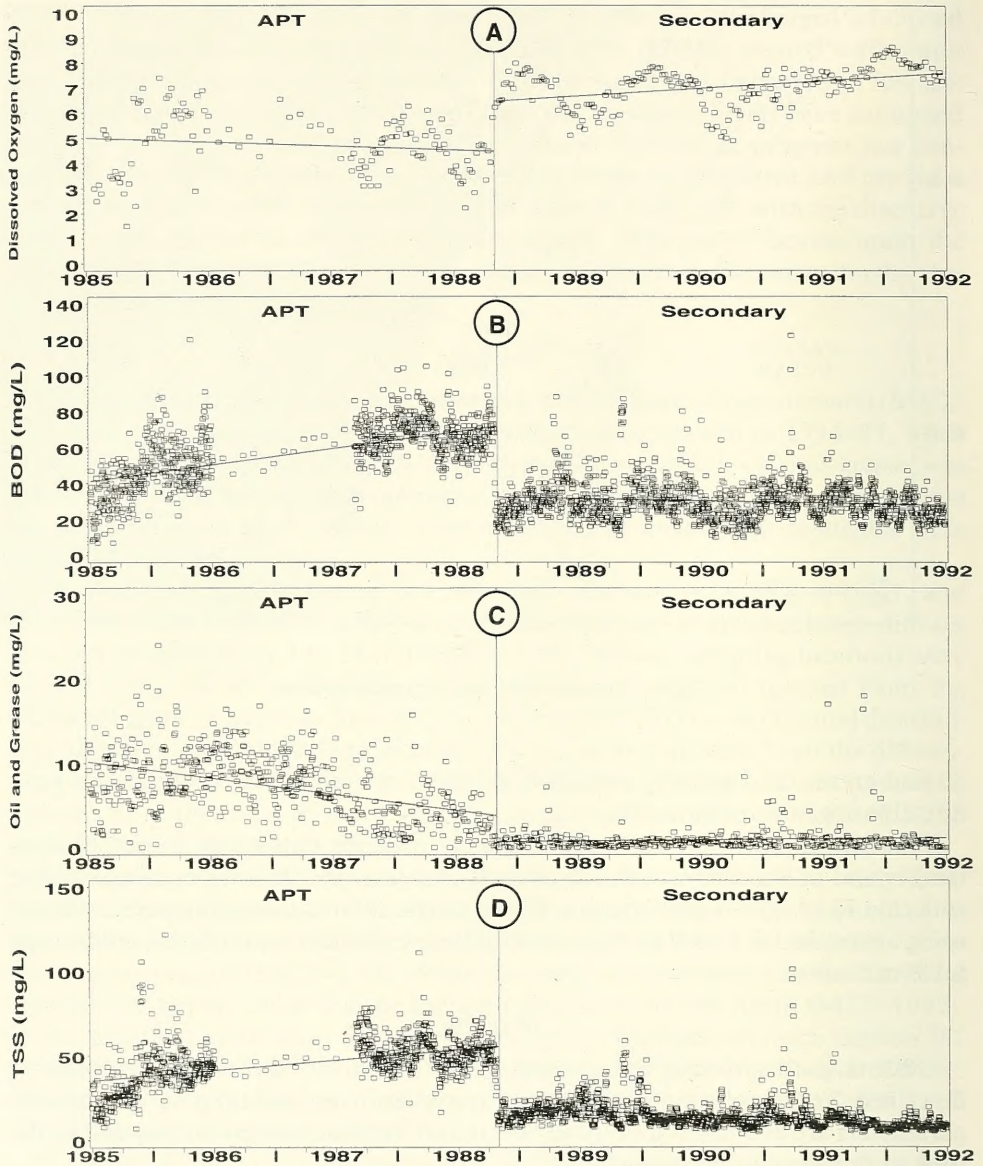


Fig. 2. Dissolved oxygen (A), BOD (B), oil and grease (C), and TSS (D) concentrations in the effluent. Regression lines during APT and secondary treatment are shown. Vertical line marks the conversion from APT to secondary treatment.

However, there was a significant increasing trend in the DO concentrations during the period of secondary treatment. The mean value for DO since the beginning of secondary treatment was significantly higher than that of the APT period (mean for APT=4.63 mg/L, mean for secondary = 6.77 mg/L, T probability = <0.01).

BOD can be used to measure the potential of the wastewater discharge to decrease receiving water oxygen levels. At Encina, effluent BOD values showed a significant increasing trend during APT ($p < 0.01$) (Figure 2B). Since the shift

to full secondary treatment in October 1988, BOD values have remained relatively constant, with mean values approximately half those measured during APT (MEC 1992).

Oil and grease concentrations showed a significant decreasing trend ($p < 0.01$) during APT and relatively constant, low concentrations during full secondary treatment (Figure 2C). Mean values during secondary treatment were significantly lower than those during APT (mean for APT = 7.37 mg/L, mean for secondary = 0.83 mg/L, T probability = <0.01).

Total suspended solids are important because the discharged particles can reduce light levels in the water column and to the benthos and can accumulate on the bottom. TSS values showed a significant increase ($p < 0.01$) over the course of APT (Figure 2D). After the start of full secondary treatment, TSS concentrations showed a slight but significant decrease with time ($p < 0.01$). Mean values were significantly different (mean for APT = 45.68 mg/L, mean for secondary = 15.70 mg/L) between the two treatment periods.

Effluent ammonia concentrations showed a significant ($p < 0.01$) increasing trend during APT and a significant ($p < 0.01$) decreasing trend during full secondary treatment; however, there was no significant difference between mean concentrations for the two treatment periods. Values for metals and toxins were consistently < 1 ppb and showed no temporal trends.

Thus, there was clearly significant improvement in effluent quality with full secondary treatment. However, measurements (temperature, DO, pH, salinity, transmissivity, secchi disk, water color, TSS, oil and grease) in the receiving water environment did not show associated changes with implementation of full secondary treatment (MEC 1992). Temperature, salinity, and pH of the receiving waters were influenced primarily by environmental factors, such as seasonality and depth, and showed no outfall-related effects. Concentrations of oil and grease in the receiving waters increased since the shift to secondary treatment; this increase was seen at both reference and ZID stations and, therefore, is considered an environmental effect, unrelated to the outfall. Although TSS values in the effluent decreased significantly after October 1988, values in the receiving waters showed no associated change. Similarly, DO values in the effluent showed a significant increase following the shift to secondary treatment; however, the change in effluent values between the two treatment periods was not apparent in measurements made at the stations closest to the discharge (ZID stations) (MEC 1992).

Sediment parameters.—Of the over 200 compounds sought in the priority pollutant analyses, only a relatively small subset (primarily conventional sediment parameters and trace metals) were consistently present in concentrations exceeding the respective method detection limits and are described in this section. The majority of priority pollutant organic compounds were detected sporadically in the sediment samples or were not detected. Temporal trend analysis for sediment contaminants also was complicated by changing analytical methods and detection limits.

From 1985 to 1992, sediment TOC concentrations ranged from 0.21 to 1.50%, and annual mean TOC concentrations ranged from 0.47 to 1.0%. No consistent temporal trends were indicated. Absolute TOC concentrations showed no indication of enhancement near the outfall. Upcoast reference Station R2, which has the greatest percentage of fine sediments, consistently had the highest TOC values.

The positive correlation of TOC and fine sediment fractions has been a consistent finding of other benthic studies (e.g., Thompson et al. 1987). When TOC concentrations were normalized to percent of the silt-clay sediment fraction, TOC concentrations were enhanced (approximately doubled) for gradient and ZID stations. This enhancement appears to be an outfall-related effect; however, the switch to full secondary treatment in October 1988 did not produce any significant change in sediment TOC concentrations near the outfall. Sediment BOD, dissolved sulfides, and oil and grease concentrations showed no indication of enhancement near the outfall, and temporal analysis was not possible due to changes in methods with time.

Trace metals present in marine environments are derived from numerous sources, both natural and anthropogenic. Enrichment of sediments with trace metals is common near wastewater outfalls and is one of the more obvious indications of sediment alterations related to wastewater discharges (Morel and Schiff 1983). Trace metals are of concern because: 1) they can exhibit enrichment factors of several magnitudes; 2) some are potentially toxic to marine organisms; and 3) the input of metals to nearshore sediments by human activity is comparable to, or exceeds, natural inputs (Katz and Kaplan 1981). Antimony, arsenic, beryllium, cadmium, chromium, cyanide, lead, mercury, selenium, and thallium concentrations were not enhanced relative to the outfall, and no temporal trends were discerned. Three metals—nickel, silver, and zinc—showed decreasing temporal trends, but there was no enhancement relative to the outfall, suggesting that these decreases were related to decreasing background levels and were not due to improved treatment levels. Lower background levels may be related to decreased runoff due to the recent drought or to increased public environmental awareness. Copper concentrations, when normalized to percent silt-clay, were enhanced at the ZID stations indicating an outfall effect; however, this enhancement was below concentrations reported for areas away from point source discharges in Southern California and representative of background levels (NOAA 1988). No long-term temporal trends were noted.

Thus, while there were clear measurements of the effectiveness of full secondary treatment on improving the wastewater effluent quality, there were fewer data supporting improvements for sediments in the receiving environment. Water column measurements and most sediment parameters provided no indication of outfall effects and/or no change related to improved treatment of wastewater.

Infaunal community.—The infaunal community consists of smaller organisms that live in the sediments or at the sediment-water interface. Infauna organisms have been variously defined, but generally are considered those organisms retained on either a 1.0 or 0.5 mm sieve (Hulings and Gray 1971; Cox 1976). Monitoring of the infaunal habitat is important because these organisms contact and often ingest sediments and particulates, which may contain contaminants. Thus, these organisms may show changes in abundance, diversity (number of species), and biomass relative to the wastewater discharge (gradients), which may indicate either enhancement or degradation of the community. Community parameters and abundances of selected species for the six stations along the 45 m depth contour are summarized in this section. Since all infaunal stations were at the same contour, the influence of depth on infaunal community structure was not analyzed.

For 1985 to 1993, the average number of species was 104 and the average

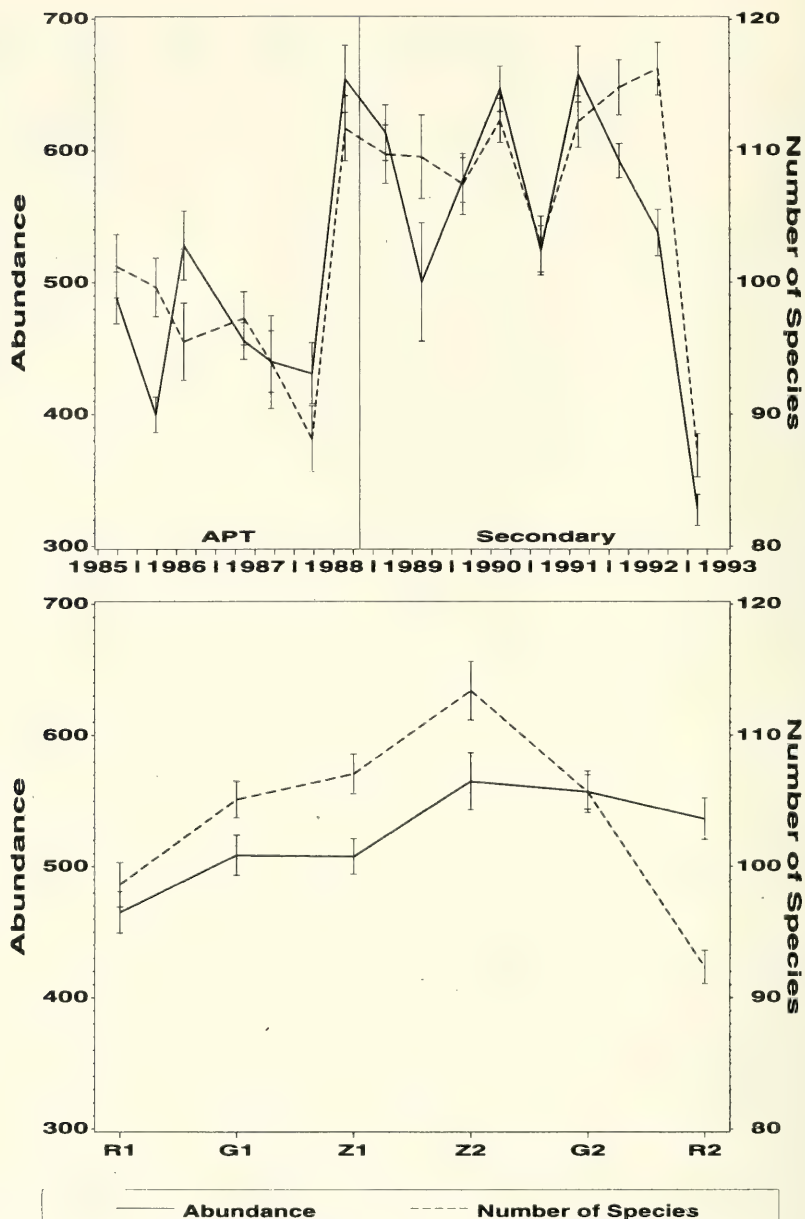


Fig. 3. Mean diversity and total abundance by survey and by station, 1985-1993. Bars indicate one standard error.

abundance was 524 organisms per sample (Table 1). Diversity was highest for the ZID boundary stations, with Station Z2 having significantly higher diversity than the other stations (Table 2). The two reference stations had significantly lower diversity than the other stations and were significantly different from each other. Upcoast reference Station R2 had the lowest diversity, which may be related to the finer sediments at this location. The gradient stations had intermediate di-

Table 2. Results of ANOVA-SNK analyses of community measures for 1985-1993. Values are not significantly different among stations joined by an underline.

Parameter	Transformation	ANOVA results (<i>P</i>)	ANOVA-SNK results					
			Z2	Z1	G2	G1	R1	R2
Number of species	none	<0.01	113.4	107.1	105.7	105.1	98.6	92.3
Abundance	none	<0.01	565.1	557.0	536.4	508.7	507.7	465.2
Biomass (g)	$\log_{10}(x + 1)$	<0.01	10.6	10.0	10.7	8.9	9.4	7.9
Dominance	rank	<0.01	35.4	35.3	34.7	33.2	31.5	26.1
Margalef Diversity	$\log_{10}(x + 1)$	<0.01	17.8	17.1	16.8	16.6	15.9	14.6
Shannon-Wiener Diversity	rank	<0.01	4.0	4.0	4.0	4.0	3.8	3.8

versity values (Figure 3), and this gradient in species richness suggests that the wastewater discharge may enhance diversity near the discharge. The average number of species for all stations in 1985 and 1990 (Table 1) was significantly higher than found for the respective 1985 and 1990 Southern California Coastal Water Research Project (SCCWRP) reference surveys (Thompson et al. 1987 and 1992). This suggests that the influence of the wastewater discharge is not degrading the environment and that a balanced indigenous population (BIP) is being maintained in the study area.

With regard to temporal trends, the highest average number of species was found in August 1992 (116.7) and the lowest was found in March of 1988 (88.1), following the large storm wave event of January 1988 (MEC 1992), and in February 1993 (87.0) (Table 1), after the winter rains and storms of January 1993 (MEC 1993). The infaunal community showed a dramatic and rapid recovery following the storm of 1988, which preceded the conversion to secondary treatment. There was no regular, seasonal pattern evident for the number of species (Figure 3). The change to full secondary treatment in October 1988 produced no resultant change in the number of species. Thus, there is no indication that the shift to full secondary treatment affected the number of species per sample. The winter storms and rains of late 1992 and January 1993 had a significant impact upon the infaunal community and indicated that a 25% decrease in community diversity is within the range of natural variability.

Margalef and Shannon-Wiener diversity showed a pattern similar to that for the number of species with regard to the reference stations in that Stations R1 and R2 had significantly lower diversity than the other stations and were significantly different from each other. Unlike for the number of species, diversity indices values at Station Z2 were not significantly higher than those for the other stations (Table 2).

Dominance represents the number of species that accounts for 75% of the total abundance. Near polluted wastewater discharges, the first sign of community degradation is typically decreasing diversity with increased abundance of pollution-tolerant species, or decreasing dominance. At Encina, dominance was significantly higher for the ZID stations and Station G1, compared to Station G2, which was significantly higher than the reference stations (Table 2). As for number of species and the diversity indices, the reference stations were significantly different from each other. There was no indication that the change to full secondary treatment had an influence on these diversity measures.

Abundances of infauna in the vicinity of organic wastewater discharge or points of environmental stress generally are elevated because some species have greater tolerances than other species and can flourish when less tolerant species are displaced (Pearson and Rosenberg 1978; Gray 1989). Thus, near moderately polluted wastewater outfalls the predicted community response is lower diversity and enhanced abundance of opportunistic species. However, as discussed above, diversity nearest the outfall was enhanced, not lowered, suggesting that the response of the infaunal community was not representative of a polluted or degraded community.

Average abundances were comparable for all stations except Station R1, which had lower abundance than the other five stations (Table 2; Figure 3). Abundance tended to be higher upcoast than downcoast. The highest average abundance was in August 1991 (658) and the lowest was in February 1993 (332) (Table 2). There was no seasonal trend or pattern evident for abundance; however, the significant effect of the winter storms in late 1992 and January 1993 was evident (Figure 3). Except for February 1993, abundances were similar or higher than comparable SCCWRP reference values, and there was no indication that full secondary treatment affected infaunal abundance. Abundance patterns relative to the discharge were not significantly enhanced; however, abundance was highest at ZID Station Z2. This slight enhanced abundance and greater increase in diversity may be due to an increase in nutrients from the Encina wastewater discharge. The lack of demonstrable, statistically negative effects upon the infaunal community strongly indicates that the Encina wastewater discharge is not characteristic of more polluted outfall areas. Furthermore, the lack of community response to full secondary treatment suggests that there may not be any significant benefits for infaunal communities to conversion to full secondary treatment at small coastal outfalls.

In order to further test for a community response to the wastewater discharge, major taxonomic groups and selected species were analyzed. Polychaetes were the most diverse and abundant taxonomic group, representing about 44% of total diversity and 54% of total abundance. Polychaete abundance and diversity showed no regular seasonal pattern or temporal trends; however, irregular and abrupt changes over the last eight years were evident (Figure 4A). In March 1988 polychaete diversity declined then increased dramatically in August 1988, after which the number of species steadily declined until February 1991. This was followed by a rapid recovery, after which both diversity and abundance plummeted, reaching an eight year low in February 1993. These dips in the temporal trends are consistent with a disruption of the sedimentary environment due to significant winter storms. While some enhancement of polychaete diversity was evident for ZID and gradient stations and abundances were higher for the upcoast ZID and

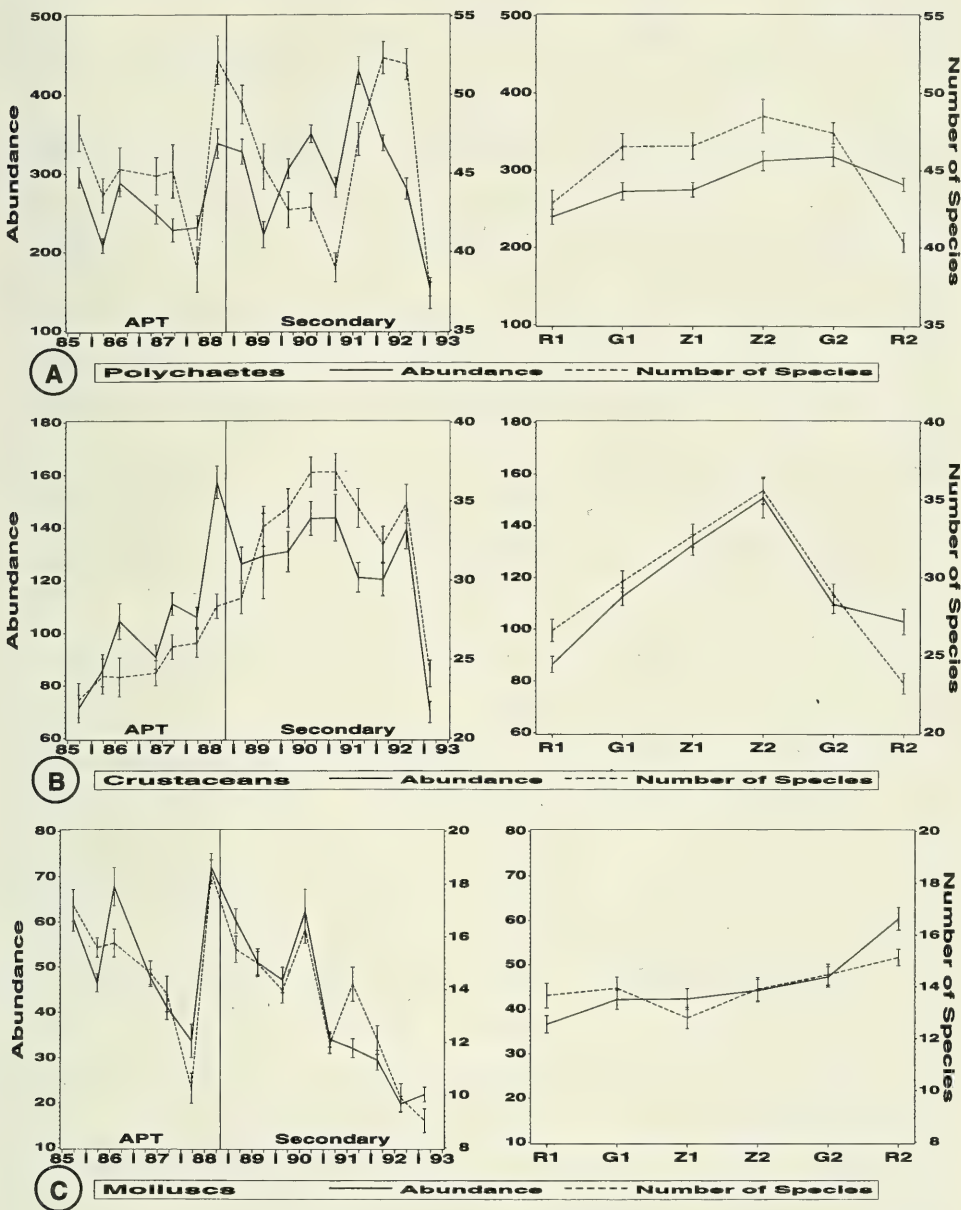


Fig. 4. Mean polychaete (A), crustacean (B), and molluscan (C) diversity and abundance by survey and by station, 1985–1993. Bars indicate one standard error.

gradient stations (Figure 4A), conversion to full secondary treatment in October 1988 had no apparent effect on polychaetes and indicated the range of natural variability.

Crustaceans were the second most abundant and diverse group of infaunal organisms. Both diversity and abundance generally increased over the first five years of the monitoring program and then decreased in summer 1991 and winter 1992 (Figure 4B). The winter storms of January 1993 significantly reduced di-

versity and abundance back to levels comparable with the start of the monitoring program. Until February 1993 both diversity and abundance had significant positive temporal trends. Conversion to full secondary treatment in October 1988 coincided with a small decrease in abundance in March 1988; however, this decrease was followed by four surveys of increasing abundance and appeared to reflect natural variation and not a response to changes in treatment levels. Diversity showed no changes relative to conversion to secondary treatment. The range of variability around October 1988 is much less than that observed for the effects of the winter storms of January 1993. The spatial patterns for crustaceans showed enhancement of both diversity and abundance centered at the outfall (Figure 4B). This enhancement probably is related to the utilization of fine organic particulates discharged from the outfall as food. This clearly is an outfall effect, but this pattern showed no change before or after the switch to full secondary treatment. While secondary treatment practices have significantly reduced suspended solids discharged into the marine environment, it is hypothesized that this decrease relates to the removal of larger sized particles and that the pattern of smaller sized particles being discharged has remained relatively unchanged with full secondary treatment. The enhancement of this taxonomic group occurred without loss of diversity for the other taxonomic groups.

Molluscan diversity and abundance were highly correlated and showed some long-term temporal trends (Figure 4C). Both diversity and abundance had two major low points over the past eight years; however, these trends occurred over many years and, unlike the polychaetes and crustaceans, were not strongly affected by major storm events. While the most recent declining trend for molluscs coincided with conversion to secondary treatment, the earlier trend of remission observed from 1985 to 1988 suggests that these long-term trends were part of natural cycles. The spatial distribution of mollusc diversity and abundance was not enhanced near the outfall, and upcoast Station R2 had the highest diversity and abundance. The observed spatial distribution and diversity of molluscs followed the fine sediment grain size patterns except for at Station Z1, which had lower diversity than might be expected. There was no indication that the wastewater discharge or the conversion to full secondary treatment had any impacts upon the molluscan community.

Echinoderm diversity and abundance generally showed increasing trends during the monitoring program with no perceptible change coinciding with the conversion to full secondary treatment (Figure 5A). Winter storm events had little effect upon echinoderms. This may be related to their preference for burial in the sediments, which makes them less sensitive to erosion and smothering by storms. Spatial diversity patterns indicated that diversity was highest downcoast (except at Station Z1) and lowest upcoast (Figure 5A), possibly showing a negative relationship with fine sediments. Abundances clearly were depressed near the outfall indicating an outfall effect.

The majority of the echinoderms were represented by a single species of ophiuroid, *Amphiodia urtica*, recognized as very sensitive to wastewater discharges. This brittle star, which was the fourth most abundant infaunal species, had depressed counts near the outfall (Figure 5A), which has been a consistent feature of every survey over the past eight years (MEC 1993). Since this species is considered to be a sensitive indicator species in Southern California, its spatial pat-

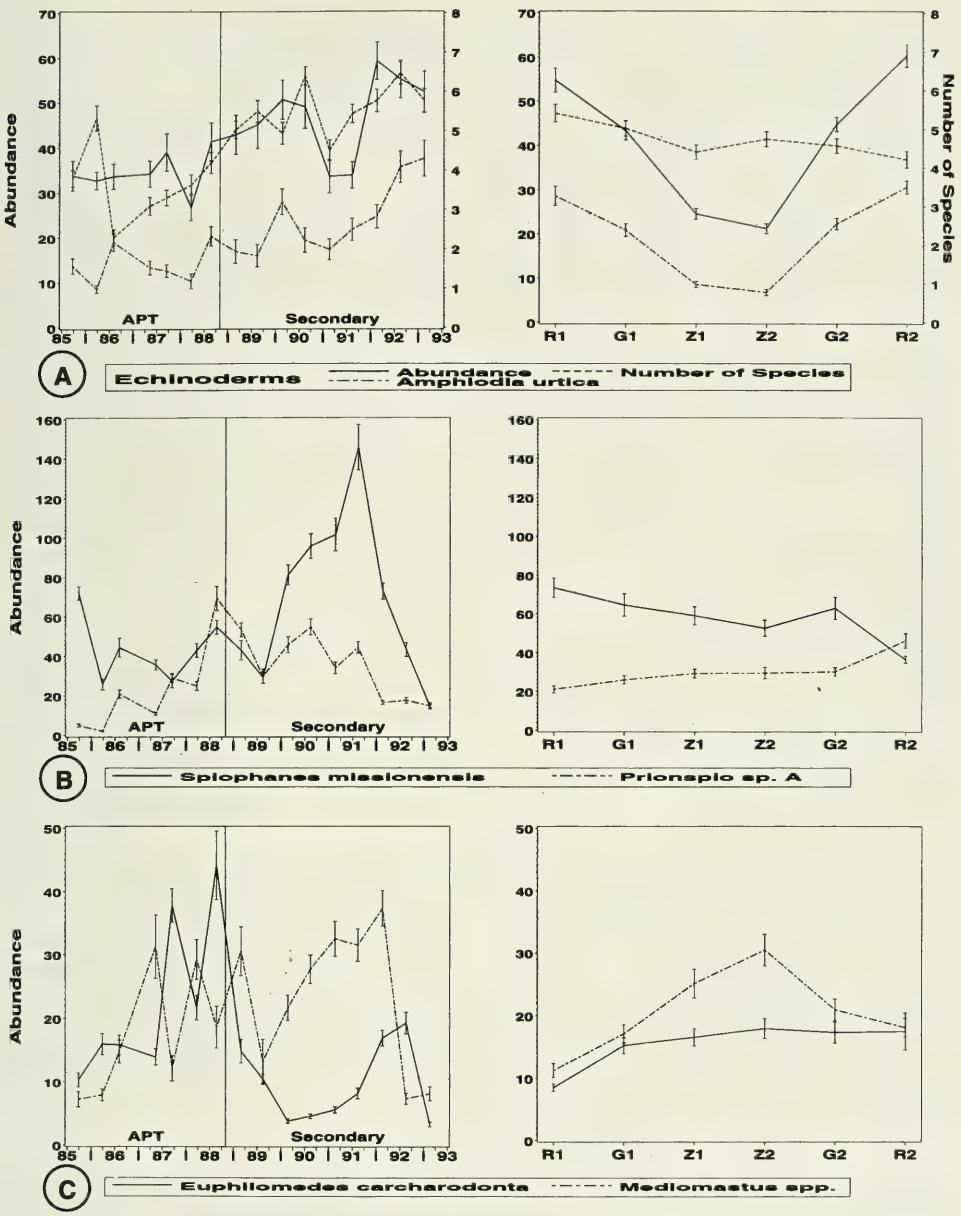


Fig. 5. Mean diversity and abundance of echinoderms (A) and mean abundance of *Amphiodia urtica* (A), *Spiophanes missionensis* (B), *Prionospio* sp. A (B), *Mediomastus* spp.(C), and *Euphilomedes carcharodonta* (C) by survey and by station, 1985–1993. Bars indicate one standard error.

terns were studied carefully for any changes in abundance relative to the discharge and treatment levels. After 4½ years of full secondary treatment, the depression of *A. urtica* abundances has not been altered (MEC 1993). This suggests that the depression of abundances near the outfall may not be related to discharge effects but rather may be due to factors independent of the wastewater discharge. One possible explanation may be related to predation effects. The outfall structure

represents a large artificial reef that harbors fish and other predators that feed upon ophiuroids. Davis et al. (1982) found foraging effects of fishes on the epifaunal community up to 200 m from an artificial reef in Southern California. Predation effects are consistent with the observed spatial patterns for ophiuroids and suggest that the depression in *A. urtica* abundance may be related to the outfall structure but is not due to the discharge.

The temporal and spatial patterns for four other abundant species were examined for outfall effects and responses to changes in treatment levels. The polychaete, *Spiophanes missionensis*, was the most abundant infaunal organism sampled. This species showed some dramatic abundance cycles that appeared to be unrelated to season or conversion to secondary treatment (Figure 5B). Spatial patterns were not enhanced near the outfall, and this species appeared to have a preference for sandy, not silty, sediments as indicated by higher abundances downcoast compared to upcoast. Another polychaete, the undescribed species *Prionospio* sp. A, was the second most abundant infaunal species. *Prionospio* sp. A also showed dramatic abundance fluctuations that were independent of season and change to full secondary treatment (Figure 5B). This species showed a spatial pattern opposite of *S. missionensis* and appeared to prefer the finer sediments upcoast compared to the sandier sediments downcoast. The wastewater discharge appeared to have little influence upon this species.

The third most abundant taxon included capitellid polychaetes in the genus *Mediomastus*. This is a taxonomically difficult group, and organisms were identified only to the generic level. *Mediomastus* spp. abundances varied over the last eight years, and no consistent seasonal pattern or response to secondary treatment was evident (Figure 5C). The spatial pattern indicated that this taxon had the highest abundance closest to the discharge (Figure 5C). While this taxon was enhanced near the outfall, the lack of change in the spatial patterns coinciding with conversion to full secondary treatment suggests that the improvements in effluent quality were not significant enough to influence this species.

The final species considered was the ostracod, *Euphilomedes carcharodonta*, which ranked fifth in total abundance. This species showed no regular seasonal pattern or temporal trends (Figure 5C), although it had lower abundances after the winter storms discussed previously. Abundance of this species was not enhanced near the outfall, and conversion to full secondary treatment had no discernable effect on temporal or spatial patterns.

Discussion and Conclusions

The change to full secondary treatment in October 1988 produced significant improvements in DO, BOD, oil and grease, and TSS in the effluent (Figure 2A-2D). However, these improvements were not detectable in the receiving waters. For the sediments, enhanced concentrations of organic carbon and copper were found near the discharge, but the level of enhancement was not affected by conversion to full secondary treatment. These enhanced levels were comparable to reference area values, which suggests that the wastewater discharge has had minimal impact to the sediments near the discharge.

The infaunal community showed few responses to the discharge. Diversity was higher near the outfall compared to reference areas (Table 2), which indicated positive enhancement of diversity and no degradation of the community. Abun-

dance was not significantly enhanced near the discharge as often has been found in association with organic wastewater outfalls (e.g., CSDOC 1991). The only negative impact was the depressed abundances of *A. urtica* near the outfall. Transition from APT to full secondary treatment in October 1988 did not result in an improved environment for this species, and full secondary treatment has not reduced factors contributing to depressed abundances near the outfall. This may indicate that the lower *A. urtica* abundances result from factors other than the wastewater discharge. It is hypothesized that reduced ophiuroid abundances may be related to predation effects caused by fish and invertebrates that utilize the habitat provided by the artificial reef structure of the diffuser. This reef effect also may contribute to the slight enhancement in abundance and greater increase in diversity of the total infauna near the discharge as compared to reference area.

These data suggest that for the parameters described, discharges from well-designed and well-managed, small coastal wastewater facilities have minimal impacts on the receiving environment. Conversion to full secondary treatment provided no significant improvements and may not be cost-effective for improving coastal water quality and minimizing biological impacts.

Acknowledgments

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Two Decades of Marine Biological Monitoring, Palos Verdes, California, 1972 to 1992

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Abstract.—Approximately 1.25×10^6 meters³ (330 million gallons) of treated wastewaters are discharged daily onto the Palos Verdes Shelf, off Los Angeles. Routine intensive marine environmental monitoring began in 1972. A brief review of effluent emissions, Palos Verdes topography, natural disturbances (El Niño, storms), and sediment histories will provide background for a 20-year summary of the Palos Verdes biota: benthic infauna, epibenthic megainvertebrates, demersal fish, kelp, and fish tissue contamination. Dramatic improvements are evident. Diverse biological assemblages are more widespread. Dover sole fin erosion has disappeared and kelp beds flourish. Decreased but continuing bioaccumulation of DDTs and PCBs is a concern, however. Historic discharges of these chlorinated hydrocarbons persist in a partly buried sediment reservoir.

The Los Angeles County Sanitation Districts serves the sewage treatment and solid waste management needs of 5 million people in 79 cities, including over 70,000 commercial establishments and industries. Each day, 1.25×10^6 meters³ (330 million gallons) of partial secondary treated wastewaters are discharged into the ocean off Palos Verdes. The submarine outfall system extends about 3 km offshore from Whites Point to a water depth of 60-meters (Fig. 1).

Treated wastewaters have been discharged off Palos Verdes for 55 years (Fig. 2). Flow and suspended solids emissions to the ocean increased with growth in the county from 1937 to 1970. Since 1970, flow to the ocean has been more stable, because of construction of upstream water reclamation plants within the Districts' Joint Outfall System.

Effluent quality has improved markedly since 1970, as a result of changes in treatment practice and increasingly stringent source control. Advanced primary treatment, partial secondary treatment, and especially improved solids handling (i.e., centrifuges), have decreased the solids mass emission rates (Fig. 2). The 1992 solids mass emission rate to the ocean was less than one-fifth that discharged in 1971.

Trace contaminant discharges decreased also, because of aggressive source control and treatment changes (Fig. 3). For example, 1992 emissions of cadmium, chromium, copper, lead and zinc are a few percent of 1971 values. The world's largest manufacturer of DDT discharged its process wastes into the Sanitation Districts' sewers from approximately 1950 to 1971 (Chartrand *et al.* 1985). DDT emissions to the ocean dropped precipitously following disconnection of Montrose Chemical from the sewer system (Fig. 3). The 1992 effluent concentration was 0.01 $\mu\text{g/l}$, equivalent to 4.6 kg/yr.

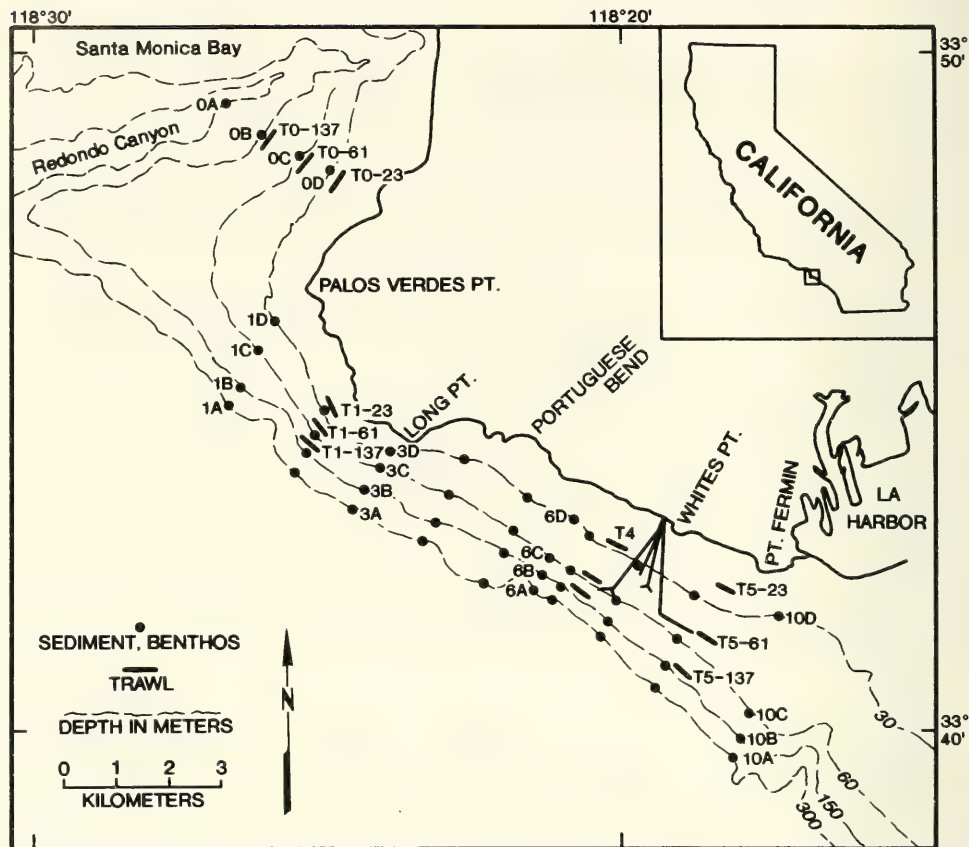


Fig. 1. Sampling sites on the Palos Verdes shelf and slope. Five of 11 benthic/sediment transects are labelled (0, 1, 3, 6 and 10); stations are located at 30-, 61-, 152- and 305-m water depth. The 4 trawl transects (T0, T1, T4 and T5) and 3 water depths sampled (23-, 61- and 137-m) are indicated. The outfall system extends offshore from Whites Point.

In the early 1970s, prior to improved source control and treatment practices, wastewater discharge significantly altered the Palos Verdes shelf environment. Sulfide-rich blackened sediments were reported, with elevated metals, DDT and PCBs in surface sediments and to 20 cm depth near the discharge (Galloway 1972; Southern California Coastal Water Research Project 1973). Concentrations decreased with distance from the outfall system. Shelf benthic infaunal assemblages were dominated by polychaetes, with many *Schistomeringos longicornis* (synonyms *Dorvillea articulata* and *Stauronereis rudolphi*) and *Capitella* spp near the outfall, and *Chaetopterus variopedatus* beds in the nearshore by Long Point (Allan Hancock Foundation 1965; Jones 1969). Crustaceans and echinoderms were rare, and many infaunal species were conspicuously absent near the outfalls.

The giant kelp (*Macrocystis pyrifera*) canopy had virtually disappeared from the Palos Verdes rocky subtidal by 1958, partly as a result of discharged effluent particulates (California State Water Quality Control Board 1964). These reduced light transmissibility in the water column, introduced a flocculent and toxicants, and buried the substrate. Aided by transplanting efforts initiated in 1967 by the Cal-

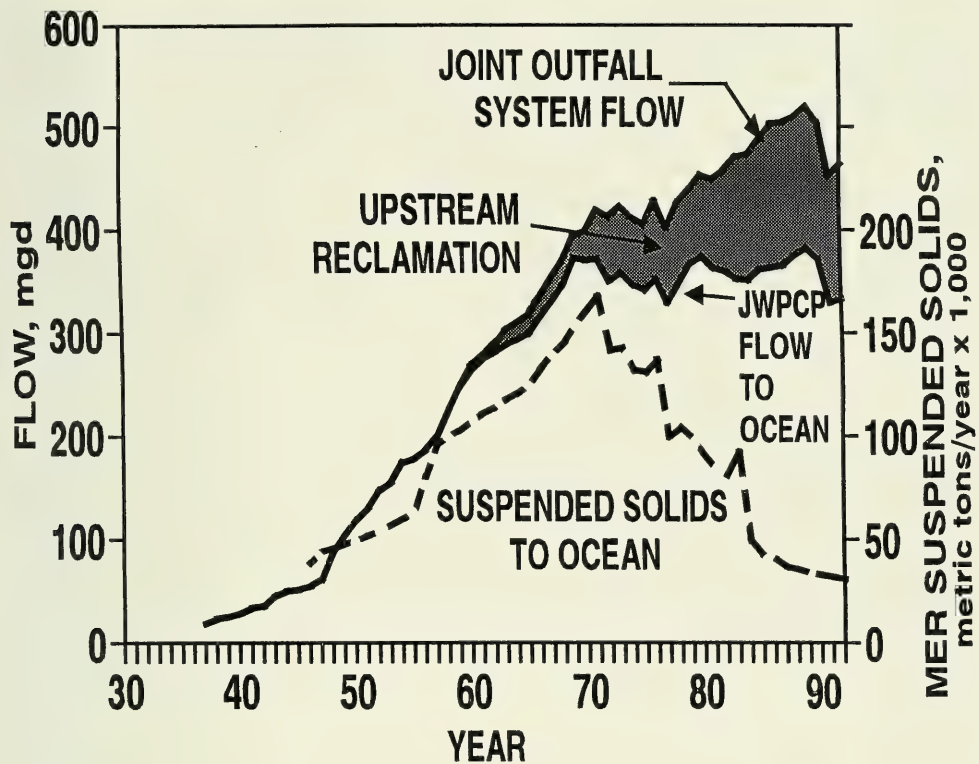


Fig. 2. Flow of treated wastewaters and mass emissions of suspended solids discharged to the ocean off Palos Verdes, 1937 to 1992. mgd = million gallons per day; MER = mass emission rate. Upper line is the Districts' entire Joint Outfall System flow.

ifornia Institute of Technology, and carried on in 1971 by the California Dept of Fish and Game, kelp were gradually reappearing along the peninsula (Wilson *et al.* 1978). In the rocky subtidal, economically important species such as *Macrocystis*, spiny lobster, abalone, and many fish species were reduced or absent (Grigg and Kiwala 1970).

In the early 1970s, in the immediate vicinity of the outfalls, demersal fish were low in number of species, diversity, abundance and biomass (Mearns *et al.* 1976; Allen 1977, 1982). Hornyhead turbot, California tonguefish, plainfin midshipman and yellowchin sculpin were rare or absent, whereas white croaker, shiner perch and curlfin sole were unusually abundant. Thirty-one of 69 species collected off Palos Verdes during 1969 to 1972 trawl surveys exhibited fin erosion (SCCWRP 1973).

DDT inputs to the Los Angeles County Sanitation Districts' sewer system were terminated in 1971 (Chartrand *et al.* 1985); widespread marine environmental contamination had been observed. Elevated DDT and PCB concentrations were reported for muscle tissues of Dover sole taken near the Whites Point outfall system (SCCWRP 1973).

The monitored area encompasses a range of environments. The geomorphology of Palos Verdes is relatively unique for Southern California. It is a coastal promontory with an exceptionally narrow (2 to 5 km) shelf: the Redondo submarine

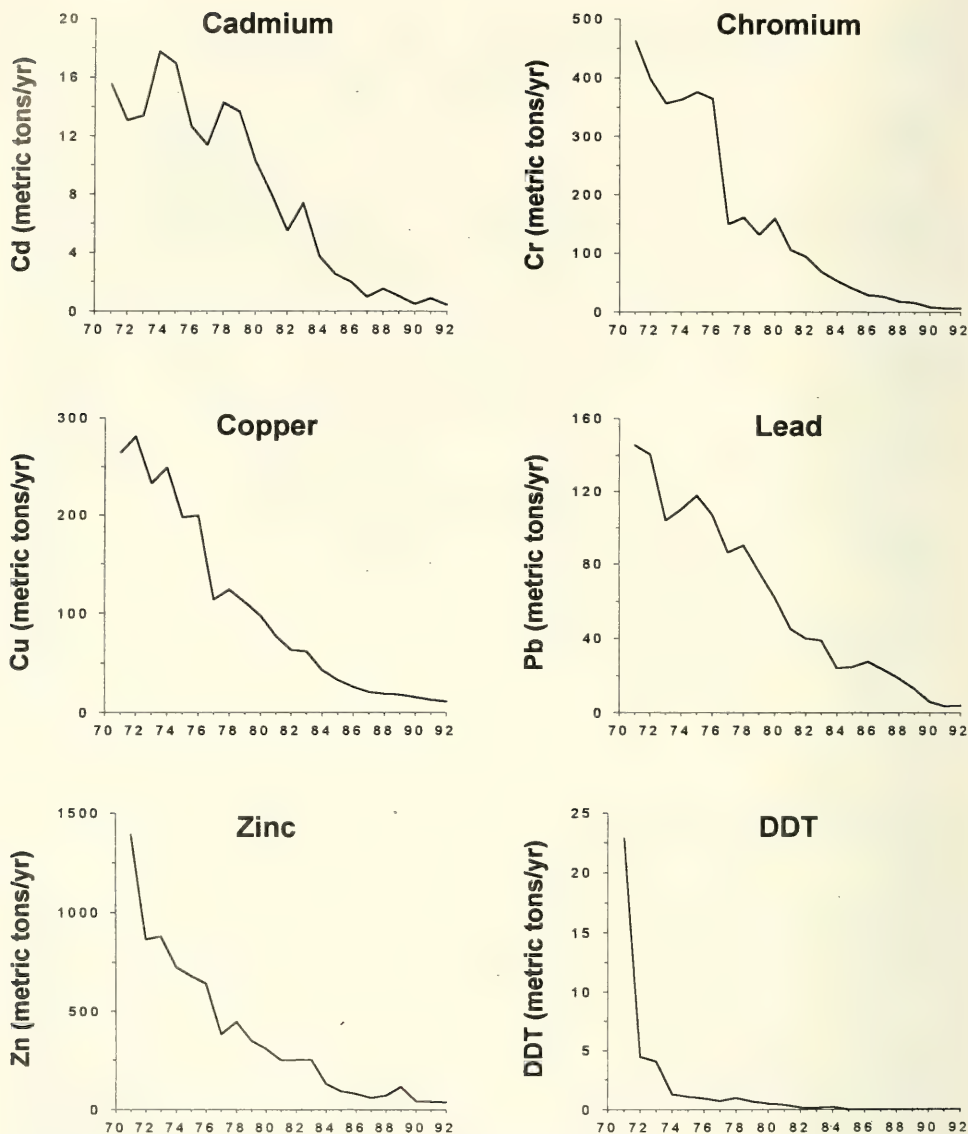


Fig. 3. Mass emissions of representative contaminants discharged to the ocean off Palos Verdes, 1971 to 1992.

canyon to the northwest and the San Pedro sea valley to the southeast separate the Palos Verdes shelf from adjacent bays. The slope begins at approximately 75 m water depth; here the slope changes from near 1° to 2 to 10° . Seasonal upwelling occurs particularly on the downcoast (southeastern) side of the Palos Verdes headland, bringing colder water and nutrients to upper waters (Grove and Sonu 1983). These natural features contribute to observed oceanographic and biological variability, both within the sampling grid and compared to the rest of the Southern California Bight.

Sediment character, food resources, and habitat quality also vary over space

and time. For example, the steep Redondo canyon transports sediments offshore and also likely serves as a funnel which brings deepwater organisms closer to shore. Upwelling enhances productivity and affects fish distributions. A narrower shelf provides fewer recruitment opportunities. Biological resources which improved over time include kelp coverage (Meistrell and Montagne 1983), and food availability (e.g., benthos, Stull *et al.* 1986a).

In addition to reductions in treated wastewater emissions and habitat variability, significant climatic perturbations were experienced on the shelf and slope in the past two decades. Major warming events (El Niños and water mass movements) occurred in 1972 to 1973, 1976 to 1977, 1981 to 1983 (the largest), 1986 to 1987, and 1991 to 1992, and there were other minor warming (and cooling) events (Graham and White 1988; Kerr 1992). A series of large storms struck the coast during the 1982 to 1983 El Niño (Dayton and Tegner 1984), and the most intense storm, in 1988, also greatly altered marine habitats (Seymour 1989). Continuous variability, of large or small scale, strongly influences biological recruitment, abundance, distribution, and succession, sometimes making it difficult to separate natural from outfall effects.

The Sanitation Districts have monitored physical, chemical and biological conditions on the Palos Verdes shelf and slope since the early 1970s. This report presents, in very abbreviated form, the results of two decades of Palos Verdes surveys of sediments and benthic infauna, kelp beds, trawled demersal fish and epibenthic megainvertebrates, and fish tissue contaminants.

Methods

Sediments and benthos.—The 44-station benthic sampling grid (Fig. 1) consists of 11 cross-shore transects, from “0” at the northwest to “10” to the southeast. Four water depths are sampled in each transect: 30-m (“D” stations), 61-m (“C” sites), 152-m (“B” sites) and 305-m (“A” sites). Stations 8C and 9C are adjacent to the outfall diffuser system.

Sediment and benthic samples were collected semiannually via a Shipek grab (surface area 0.04 square meters, 3 to 4 replicates) from winter 1972 to winter 1980 and via a Van Veen grab (area 0.1 sq.m, typically no replicates) from summer 1980 to summer 1992. For the biology, benthic infauna retained on a 1 mm mesh screen were identified to lowest practicable taxon and wet weights (including mollusc shells) were measured. For surface sediment properties, the top 5 cm of Shipek grab samples and the top 2 cm of Van Veen grabs were analyzed. For sediment organic nitrogen measurements, ammonia was removed and then the sample was digested by Kjeldahl procedures. Metals were processed by Parr bomb digestion and analyzed by inductively coupled plasma and atomic absorption spectroscopy techniques. Organics were extracted with an acetone/hexane mixture and analysis was performed by gas chromatograph equipped with 2 columns and 2 electron capture detectors. Sediment cores were collected via a large bore gravity corer, 12.5 cm in diameter (Bascom *et al.* 1982). Storage and analysis of 2 cm segments is described in Stull *et al.* (1986b).

Kelp.—Aerial surveys conducted by the California Dept of Fish and Game provide data on the areal extent of Palos Verdes giant kelp (*Macrocystis pyrifera*) beds.

Trawl fish and invertebrates.—The grid of 12 stations includes 4 transects ex-

tending perpendicular from shore (T0, T1, T4 and T5), each sampled at 23-, 61- and 137-m (Fig. 1). Semiannual or quarterly surveys were conducted, using an otter trawl with a 7.6-m headrope, 3.8 cm (stretch) body mesh, and 1.3 cm (stretch) cod-end mesh. The trawl was towed on the bottom along the isobath of each station for 10 min at approximately 1m/sec. Demersal fish and megabenthic invertebrates were identified to the lowest possible taxon, counted, measured, examined for external anomalies, and weighed. Data are available from 1978 to 1992 for invertebrates and 1973 to 1992 for fish.

Tissue contamination.—Dover sole (*Microstomus pacificus*, 18 to 21 cm standard length (size class), were collected by trawls, at 61- and 137-m depth, from transects T0, T1 and T4. Muscle samples were often analyzed as composites. Kelp bass (*Paralabrax clathratus*) were collected in three zones, Whites Point, Long Point, and Palos Verdes Point, at 6-to 25-m water depth (Fig. 1). Muscle tissues were analyzed from individual kelp bass.

For DDT and PCBs analyses, tissue samples were homogenized with acetonitrile, followed by a series of hexane extractions; the extract was concentrated and cleaned up with florisil before analysis by gas chromatography (Young *et al.* 1976). For lipid analyses, a water/methanol/chloroform solvent mixture was used; the lipid partitions in the chloroform layer which is evaporated prior to gravimetric determination of the residue.

Results

Sediments.—Surface sediment surveys reveal a broad elliptical band of finer grained, more organically enriched, porous silt across the central Palos Verdes shelf and slope. Highest contaminant distributions are found at and northwest of the outfall, at shelf (60-m) and upper slope (150-m) depths (Figs. 4 and 5). The elliptical distribution is related to wastewater discharge: it is skewed to the northwest because that is the dominant direction of subthermocline currents.

The areal extent and the maximum concentrations of surface sediment organic nitrogen and chromium have declined since the early 1970s (Figs. 4 and 5). Similar reductions have been observed for other trace contaminants, including metals and chlorinated hydrocarbons.

There is a partly buried reservoir of historically discharged contaminants on the Palos Verdes shelf and slope. Fig. 6 illustrates the alongshelf, 60-m distribution, and the cross-shore (transect 6; 30- to 305-m depth) distribution of the persistent DDT isomer, p,p'-DDE. Other contaminants, such as metals, also exhibit highest buried peak concentrations at 10 to 25 cm along the 60-m discharge depth.

Benthos.—In 1992, benthic abundance and biomass are highest along the upper slope 152-m isobath (Figs. 4 and 5); the bivalve *Parvilucina tenuisculpta* thrives in this zone. The number of species is highest in the nearshore, and it decreases offshore. There tend to be fewer taxa in the zone northwest and offshore of the outfall.

Major improvements occurred in the Palos Verdes benthos from 1974 to 1992 (Figs. 4 and 5). The number of species and the dominance index increased. Dominance (per Swartz *et al.* 1985) is the number of species which account for 75% of the total individuals in a sample. Benthic assemblages became more balanced: there is no longer an overwhelming numerical dominance by just a few species.

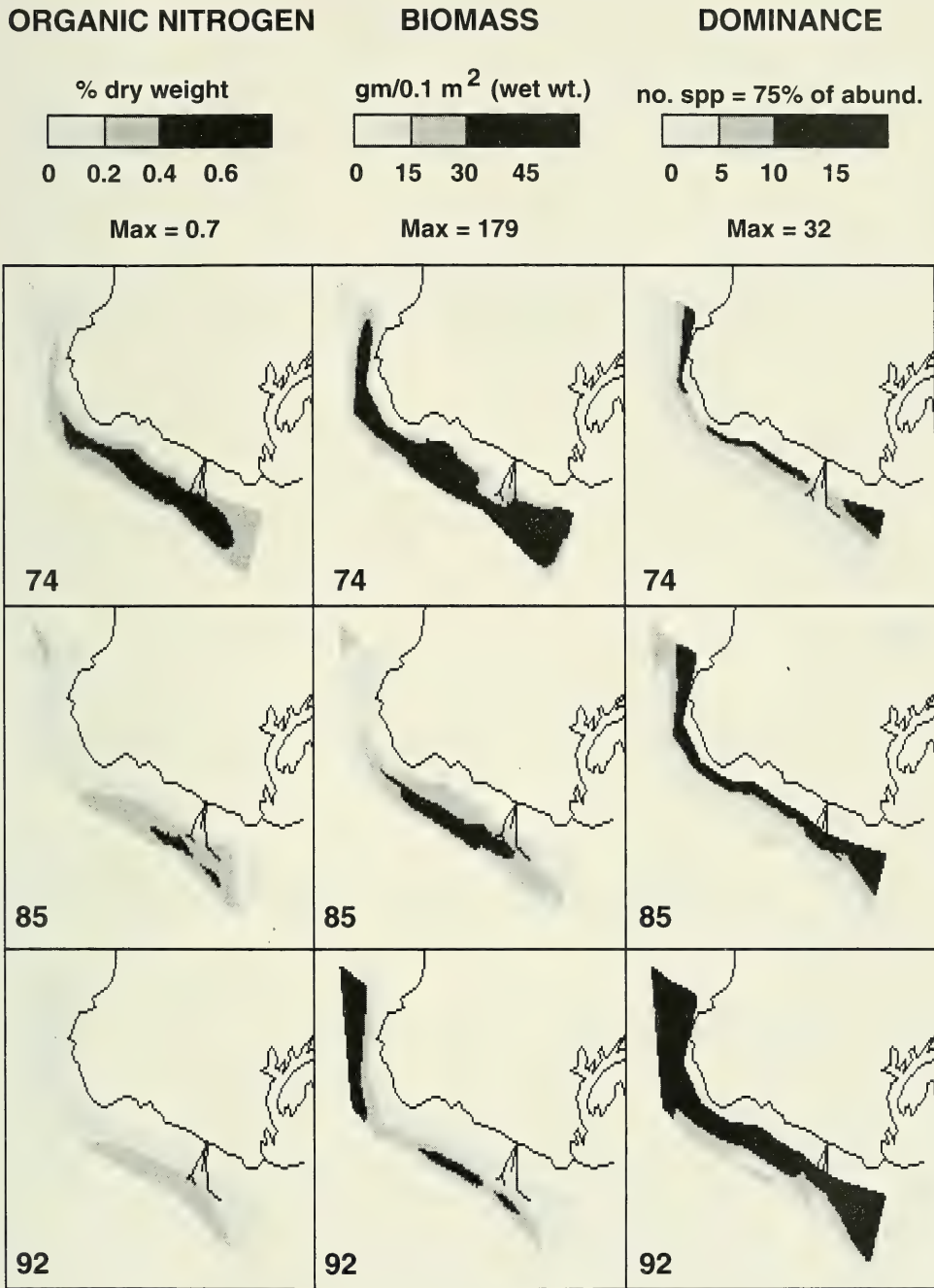


Fig. 4. Palos Verdes surface sediment organic nitrogen concentrations, and benthic infaunal biomass and dominance, 1974, 1985 and 1992.

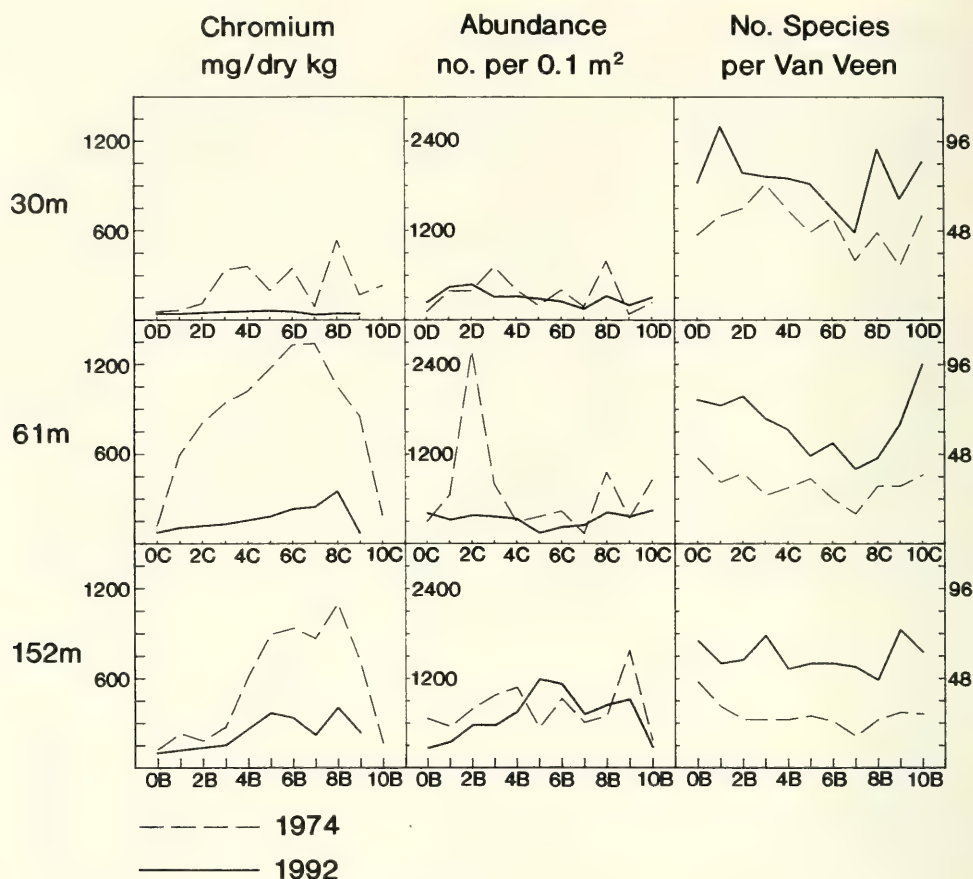


Fig. 5. Palos Verdes surface sediment chromium concentrations, and benthic infaunal abundance and number of species, 1974 and 1992. Stations along 3 depth transects are shown: 30-m ("D" stations), 61-m ("C"), and 152-m ("B").

Many organisms previously absent from the mid-shelf progressively encroached upon the outfall area. Enhanced biomass declined.

Benthic succession, 1972 to 1992, is illustrated for Station 4C, located about 5.5 km northwest of the outfalls (Fig. 7). Notable are the decreases in sediment organic enrichment (and contamination), the biological variability, the increases in numbers of species, and the pattern of species replacements. In 1972, there were many small, subsurface deposit feeding annelids (e.g., *Schistomeringos longicornis*). A very high biomass of the echinuran *Listriolobus pelodes* occupied the mid-shelf from 1973 to 1977; they significantly modified the benthic habitat. *Listriolobus* and its associates, including the clam *Mysella tumida* and the polychaetes *Mediomastus*, *Prionospio* and *Tharyx*, thrived. When the echinuran populations declined, conditions were unstable, and *Capitella* and *Nereis procera* (polychaetes) recruited into the area. The clams *Parvilucina tenuisculpta* and *Tellina carpenteri* became more common. The small brown ostracod *Euphilomedes carcharodonta* thrived in the early 1980s and 1990s. The burst of *Spiophanes missionensis* in the early 1980s was associated with strong El Niño conditions

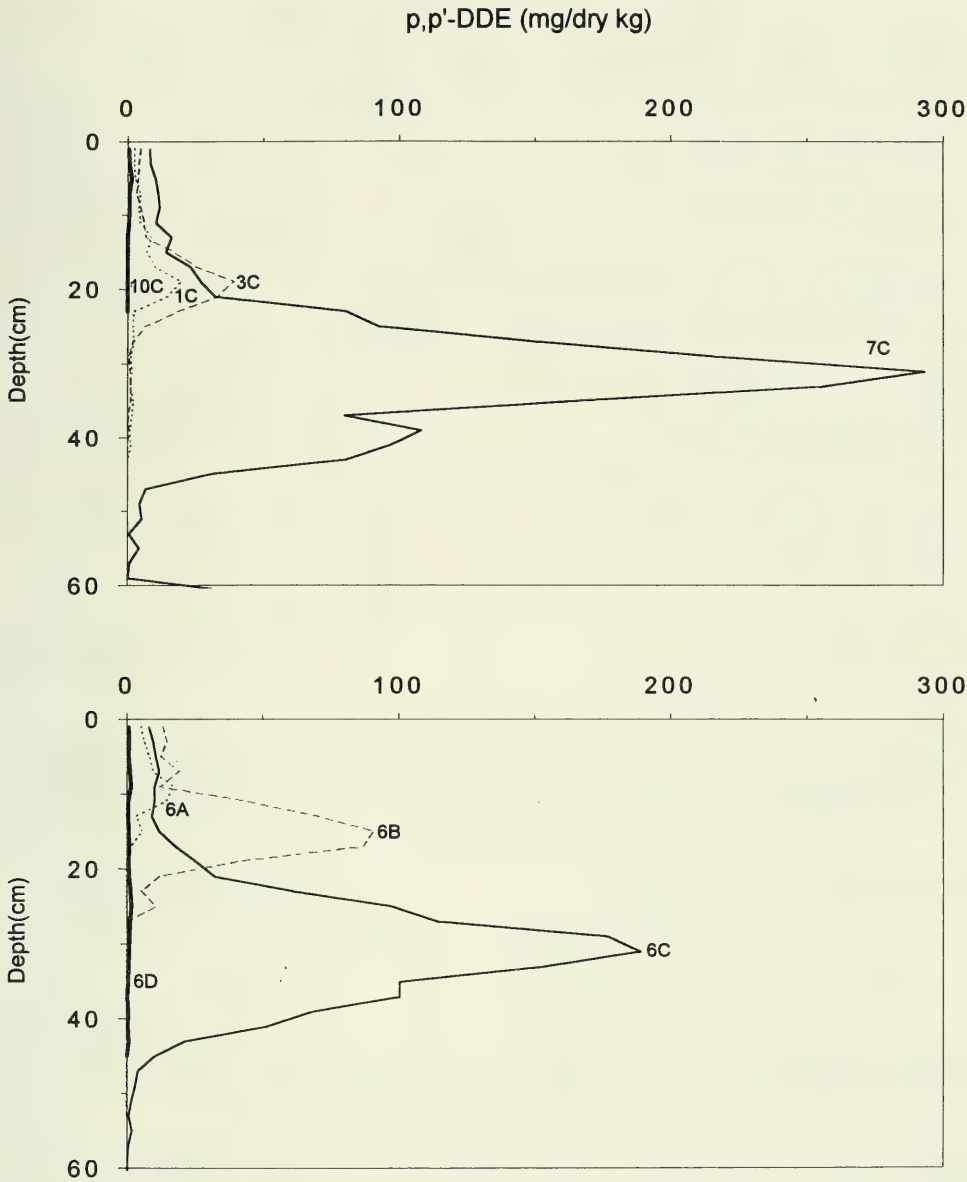


Fig. 6. p,p'-DDE distribution in Palos Verdes sediment cores taken in 1991 along the 61-m isobath (stations 1C, 3C, 7C, 10C) and in a cross-shore transect (6D = 30-m depth; 6C = 61-m; 6B = 152-m; 6A = 305-m).

and storms. The polychaete *Pectinaria californiensis* dominates station 4C assemblages in the 1990s.

Kelp. — Kelp beds (*Macrocystis pyrifera*) now flourish off Palos Verdes (Fig. 8). They gradually became reestablished along the peninsula during the 1970s, as a result of transplanting efforts and improvements in effluent quality (Meistrell and Montagne 1983). Also important to the return of kelp biomass were sea urchin (grazer) control, harvesting of other algae, and selective pressure on urchin com-

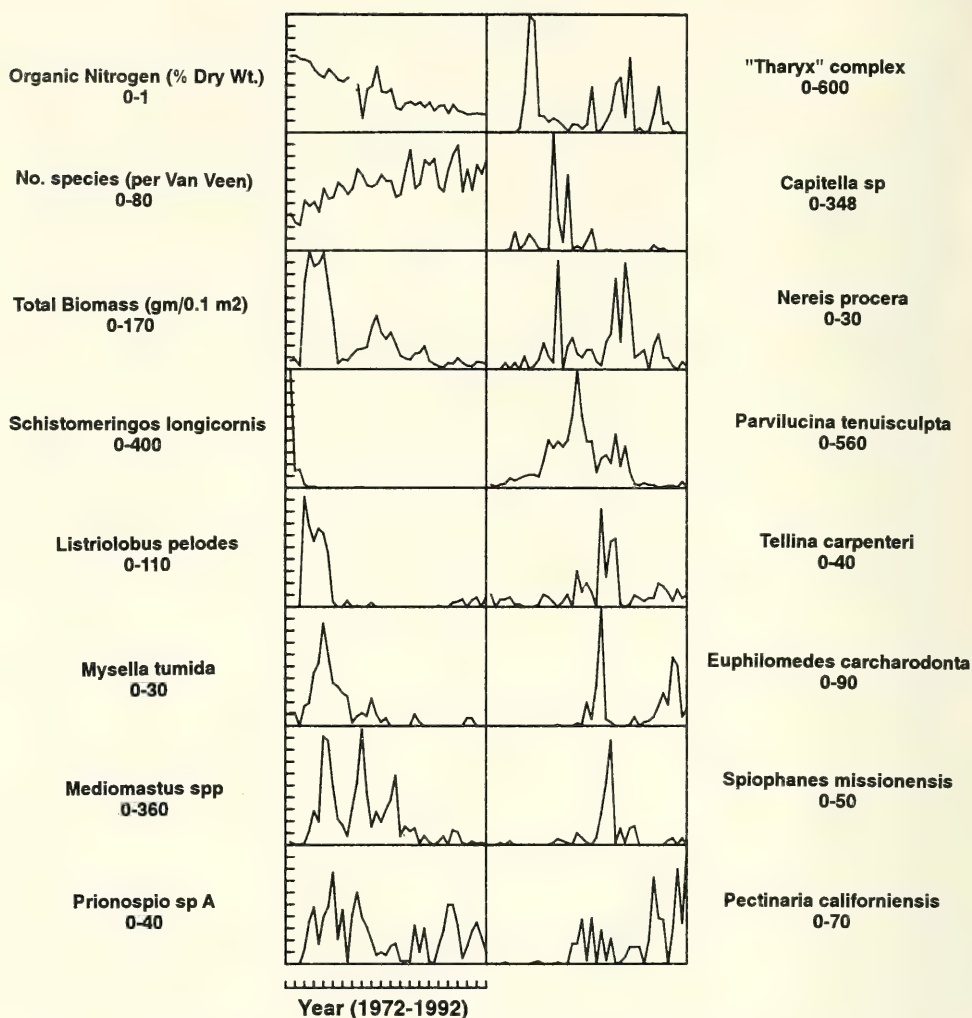


Fig. 7. Changes in surface sediment organic nitrogen and in benthic infaunal assemblages at Palos Verdes 61-m station 4C, 1972 to 1992. Scales for different parameters vary, as indicated below each variable name. For individual species, abundances are per Van Veen grab (area 0.1 m²).

petitors and predators (Wilson *et al.* 1980). Winter storms periodically destroy kelp beds all along the California coast (e.g., Wilson and Togstad 1983). However, compared to other areas, the Palos Verdes beds have recovered very quickly after storms (Wilson, pers. comm.). Movement of the Portuguese Bend landslide, 3.5 km west of the outfall system, accelerated in 1978; on average 200,000 metric tons were released per year in the 1980s (City of Rancho Palos Verdes 1986). This turbidity and sedimentation is a major impact to the Whites Point kelp beds and the rocky subtidal community. The early 1990s decline in kelp apparently results from a natural episode of increased grazing pressure from expanding sea urchin populations (*Strongylocentrotus franciscanus*, *S. purpuratus* and *Lytechinus pictus*) (J. Meistrell, pers. comm.).

Trawl invertebrates.—Palos Verdes epibenthic megainvertebrates were taken,

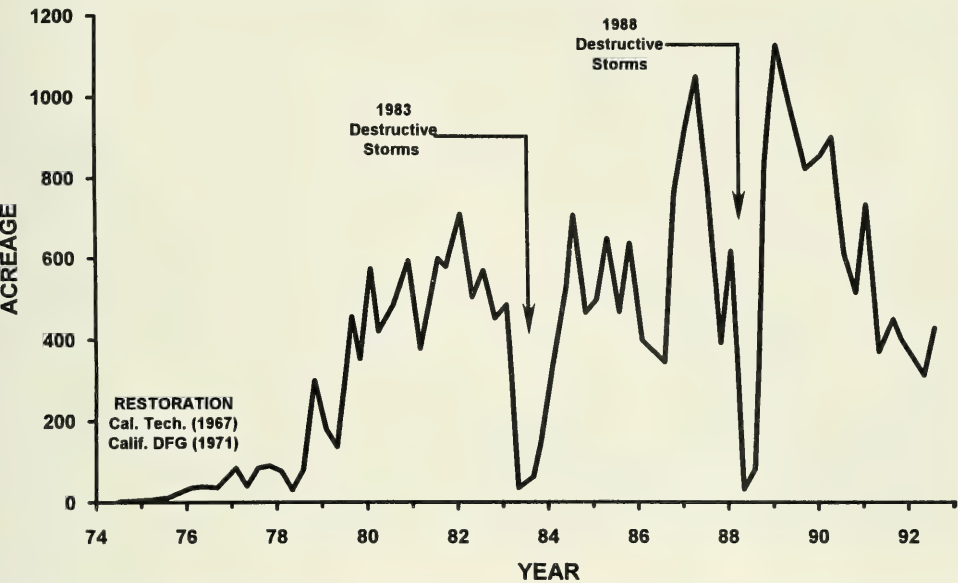


Fig. 8. Palos Verdes giant kelp (*Macrocystis pyrifera*) canopy, 1974 to 1992. Data from California Dept. of Fish and Game.

with demersal fish, by otter trawl. The inner shelf (23-m), outer shelf (61-m) and upper slope (137-m) were sampled. Invertebrate catches fluctuated markedly, both temporally (1978 to 1992) and spatially (e.g., with depth and outfall distance). Arthropods and echinoderms dominated the catches (Fig. 9). The three dominant

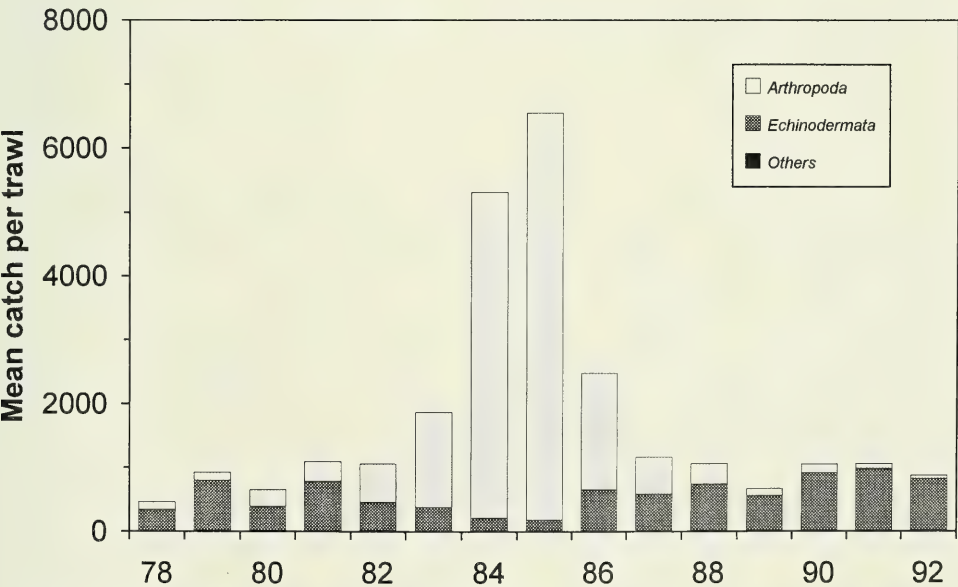


Fig. 9. Palos Verdes epibenthic invertebrate catches, 1978 to 1992. Catch is the mean of quarterly 10-minute otter trawls at the 12 sites: transects T0, T1, T4 and T5 at depths 23-, 61- and 137-m.

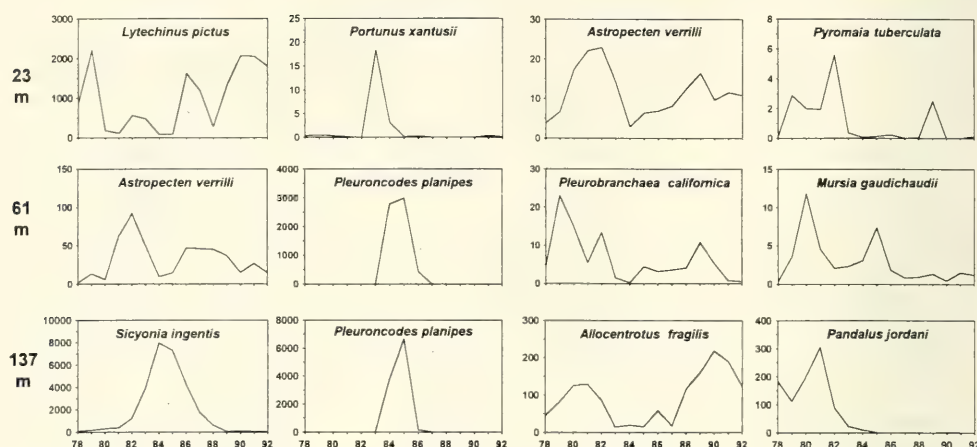


Fig. 10. Representative invertebrates trawled off Palos Verdes, 1978 to 1992. Catch is mean of quarterly 10-minute trawls at 4 sites (T0, T1, T4, T5) at indicated depth (23-, 61- or 137-m).

taxa were *Sicyonia ingentis* (ridgeback rock shrimp, 40% of the 15-year invertebrate catch), *Lytechinus pictus* (white sea urchin, 30%), and *Pleuroncodes planipes* (pelagic red crab, 25%).

Echinoderms were the most numerous in the 1990s, with smallest populations in 1984 and 1985 (Fig. 9). Representative species are plotted in Fig. 10. *Lytechinus pictus* (white sea urchin) dominated shelf (23- and 61-m) catches, especially near the Redondo Canyon (T0). Since the late 1980s, large populations also occur across the entire 23-m isobath, including inshore of the outfalls. Smallest 23-m catches were taken after storms. *Allocentrotus fragilis* (fragile sea urchin) was common on the upper slope (T1-137; T5-137 from the late 1980s) except during and following the El Niño and storms. Fewer were taken near the outfall (T4-137). *Astropecten verrilli* (California sand star) was most common on the shelf (T0-, T4- and T5-61), and in 1982; fewest were caught after El Niños (1978 and 1984).

Arthropods increased markedly in 1983, flourished in 1984 and 1985, and declined from 1986 (Fig. 9). Representative species are plotted in Fig. 10. *Sicyonia ingentis* (ridgeback rock shrimp) was very abundant on the upper slope (especially T0- and T5-137) from 1983–1986, following El Niño. *Pleuroncodes planipes* (pelagic red crab) was abundant in 1984 and 1985, particularly in the upper slope outfall area (T4-137). *Pandalus jordani* (a northern ocean shrimp) was common by Redondo Canyon (T0-137), 1978 to 1982. It declined following the 1982 to 1983 El Niño and did not return. *Portunus xantusii* (Xantus swimming crab) was abundant on the inner shelf near the outfalls (T4- and T5-23) in 1983. *Pyromaia tuberculata* (inner shelf, 23-m) and *Pleurobranchaea californica* and *Mursia gaudichaudii* (outer shelf, 61-m) were less abundant near Redondo Canyon (T0) than elsewhere on the shelf.

Trawl fish.—Flatfish (Pleuronectiformes) and rockfish (Scorpaenidae) dominated the Palos Verdes soft bottom demersal fish fauna, 1973 to 1992 (Fig. 11). Other groups were most abundant in 1983, 1977 and 1988. Assemblages varied over time, and by depth, distance from the outfall system, and site. The seven

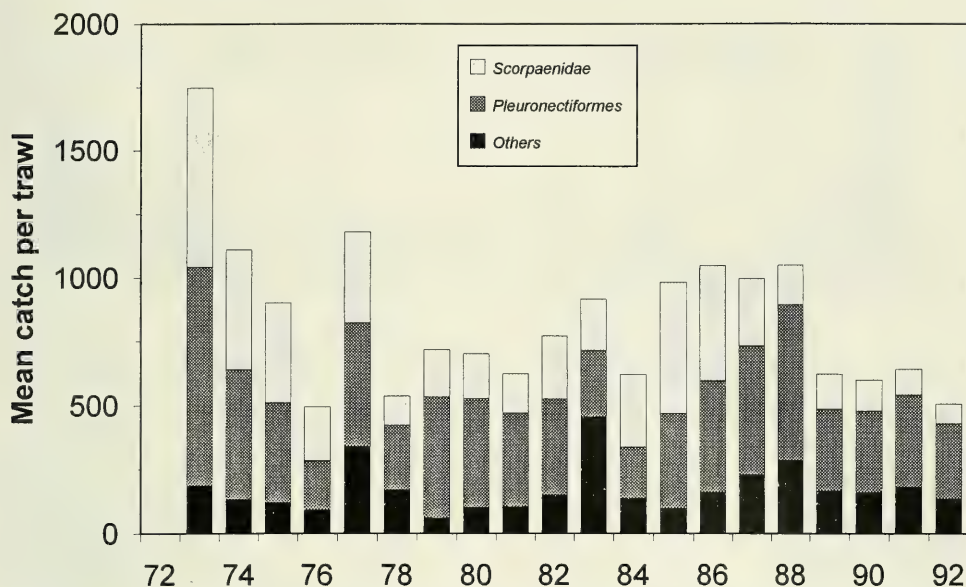


Fig. 11. Palos Verdes demersal fish catches, 1973 to 1992. Catch is mean of semiannual or quarterly 10-minute otter trawls at 12 sites: transects T0, T1, T4, T5 at depths 23-, 61-, and 137-m.

most numerous species were Dover sole (*Microstomus pacificus*, 18% of the 20-year catch), striptail rockfish (*Sebastes saxicola*, 9%), slender sole (*Eopsetta exilis*, 8%), Pacific sanddab (*Citharichthys sordidus*, 8%), plainfin midshipman (*Porichthys notatus*, 7%), yellowchin sculpin (*Icelinus quadriseriatus*, 7%), and speckled sanddab (*Citharichthys stigmaeus*, 6%).

Figs. 12 to 14 combine data from all 4 stations within each of the 3 isobaths sampled (23-, 61-, 137-m): species on the left of each figure decreased in abundance over time, and species on the right tend to have increased. Many species rare in the 1970s became common in the 1980s and 1990s, including slender sole, plainfin midshipman, blackbelly eelpout (*Lycodopsis pacifica*), and gulf sanddab (*Citharichthys fragilis*) at 137-m, California tonguefish (*Symphurus atricauda*), longspine combfish (*Zaniolepis latipinnis*), hornyhead turbot (*Pleuronichthys verticalis*), and bigmouth sole (*Hippoglossina stomata*) at 61-m, and California halibut (*Paralichthys californicus*), longspine combfish, hornyhead turbot, and fantail sole (*Xystreurus liolepis*) at 23-m. Concurrently, previously abundant species became less common, such as Dover sole, striptail rockfish, splitnose rockfish (*Sebastes diploproa*), and rex sole (*Errex zachirus*) at 137-m, speckled sanddab, English sole (*Pleuronectes vetulus*), curlfin sole (*Pleuronichthys decurrens*), and white seaperch (*Phanerodon furcatus*) at 61-m, and striptail rockfish, white croaker (*Genyonemus lineatus*), calico rockfish (*Sebastes dallii*), and shiner perch (*Cymatogaster aggregata*) at 23-m.

Fin erosion.—Dover sole (*Microstomus pacificus*) is a deepwater flatfish which prefers muddy bottoms and benthic prey. Juveniles settle on the shelf and gradually move downslope over their lifetime (Hunter *et al.*, 1990).

Fin erosion was very common among 137-m Palos Verdes Dover sole in the 1970s (Fig. 15). Highest incidences of fin erosion were found at nearer-outfall (T4 and T5) stations and the syndrome was rare at the most distant site (T0). Frequency

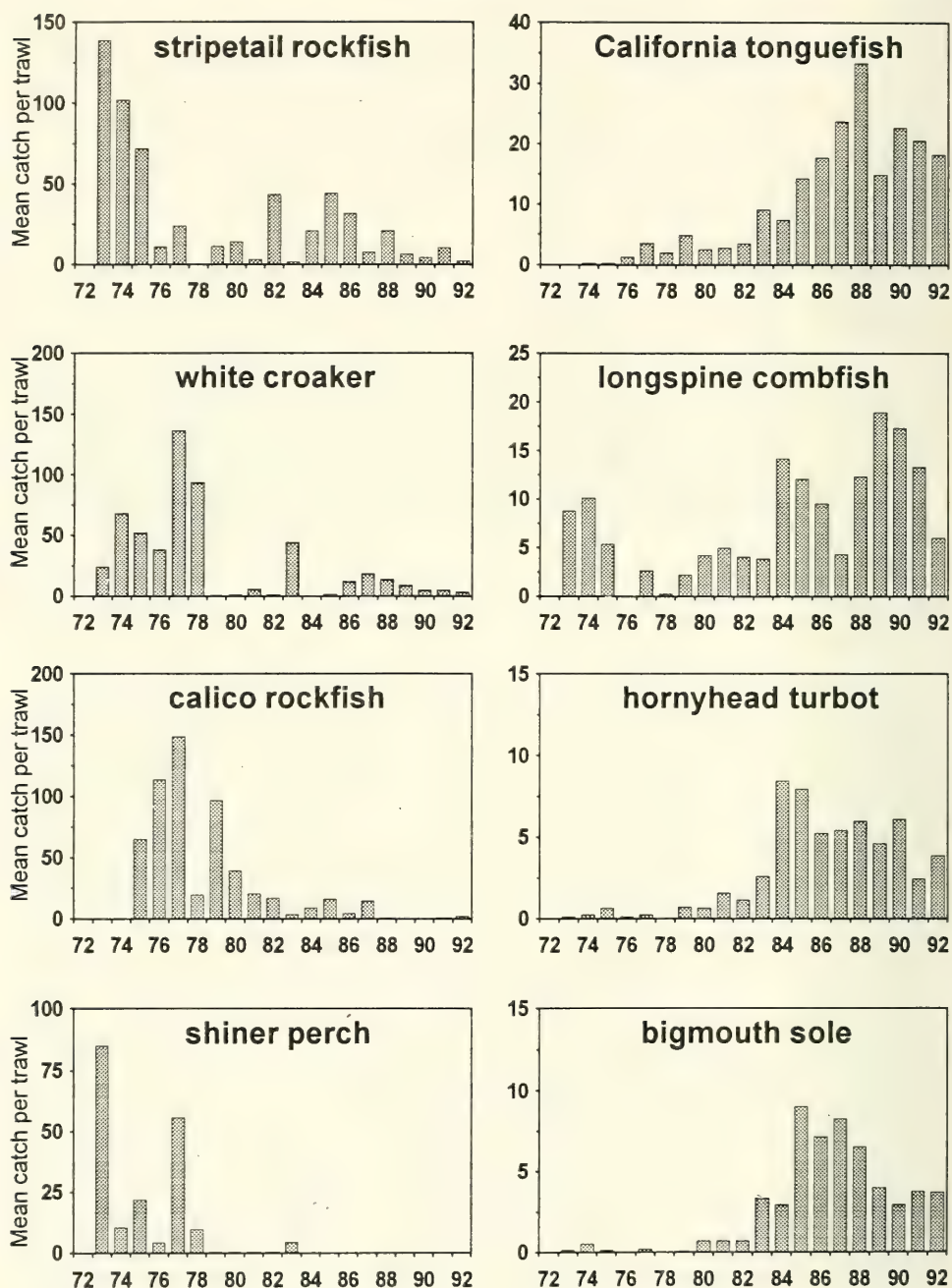


Fig. 12. Palos Verdes demersal fish, 23-m depth, 1973 to 1992.

has been very low at all 137-m sites since 1986. Severity of the syndrome declined over time; typically in the 1980s only a very small section of the mid-dorsal fin was afflicted, as compared to near total losses of most fins in the early 1970s. Trends were similar along the 61-m isobath, where fewer Dover sole were taken.

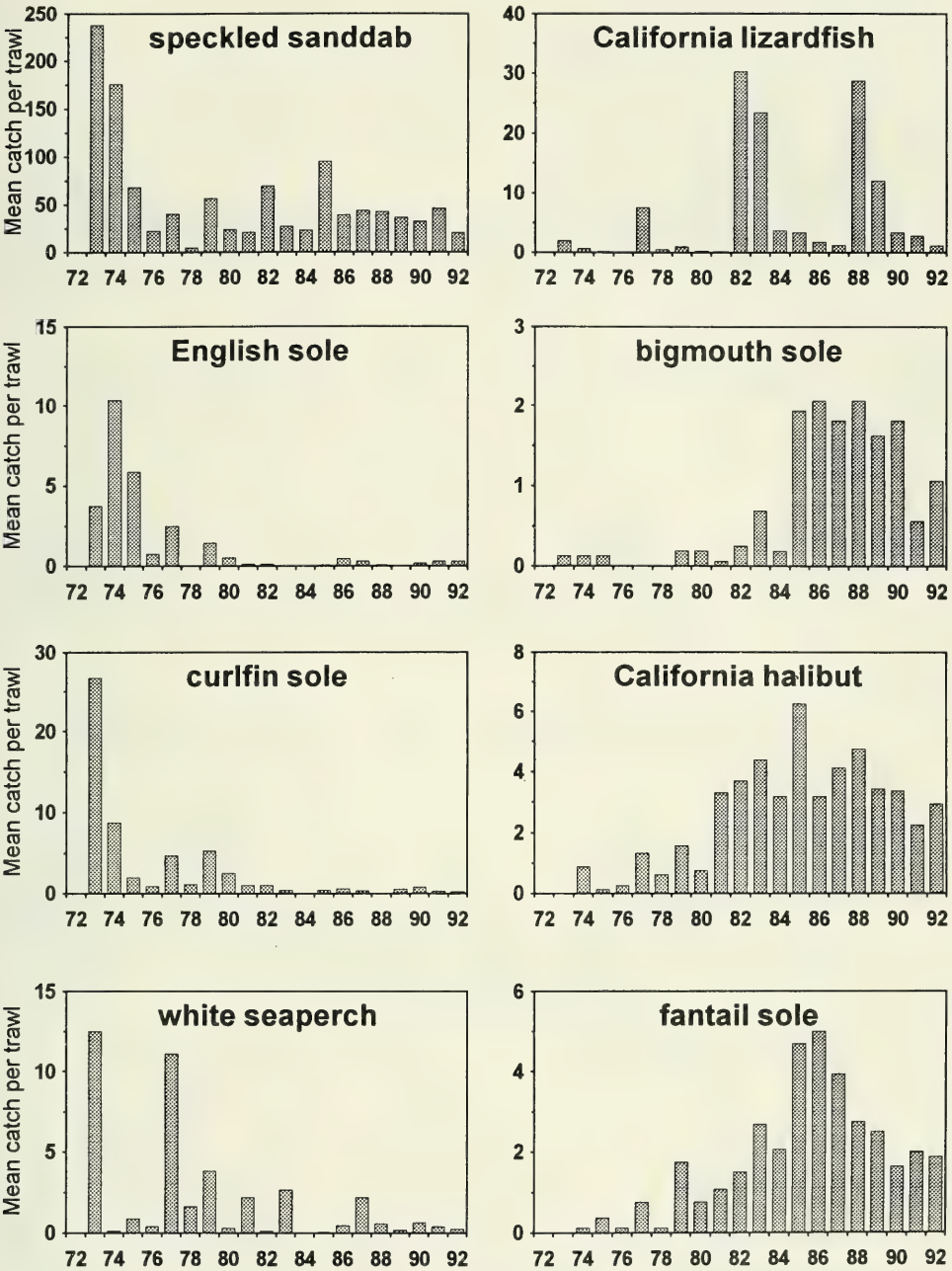


Fig. 13. Palos Verdes demersal fish, 61-m depth, 1973 to 1992.

Tissue Contaminants.—Dover sole is not harvested for human consumption in the Southern California Bight. In general, Dover sole muscle tissue DDT and PCB concentrations were higher nearer the outfall and were highest in the early 1970s (Fig. 16). Muscle concentrations decreased significantly from the early 1970s. However, concentrations over 5 mg/kg, wet weight (5 ppm wet wt) are

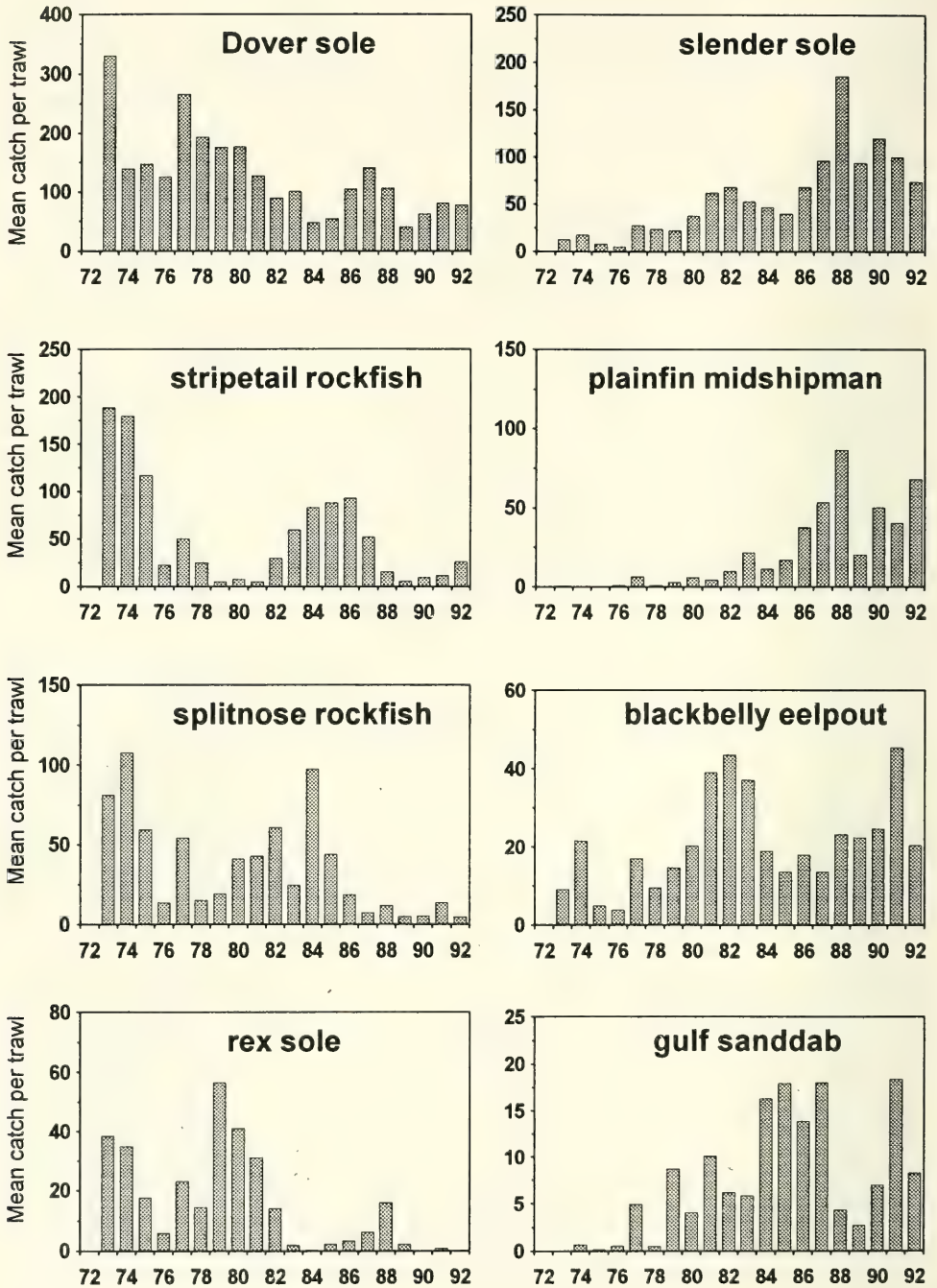


Fig. 14. Palos Verdes demersal fish, 137-m depth, 1973 to 1992.

still common. Muscle tissue PCB levels tend to be 15 to 20 times lower than for DDT. Only general trends can be interpreted from Fig. 16, since concentrations vary among individuals, and season, sample location, sample size, and compositing practice were not standardized throughout the two decades.

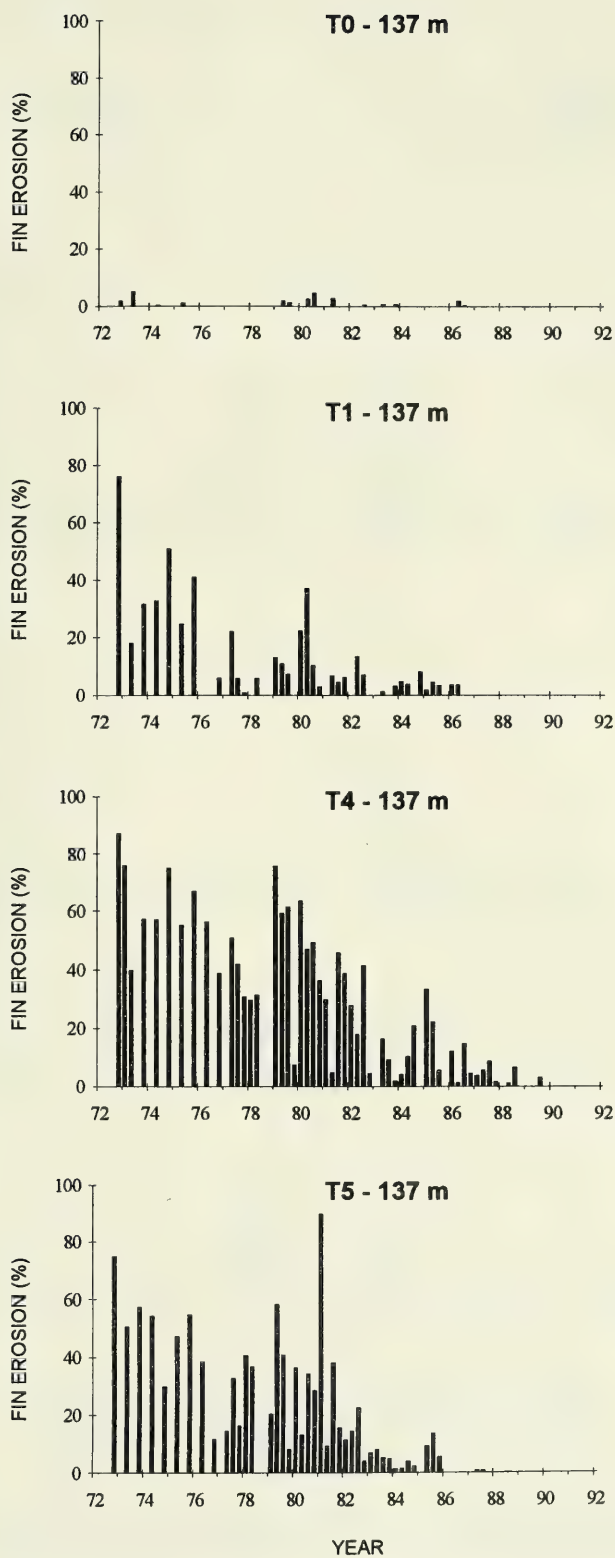
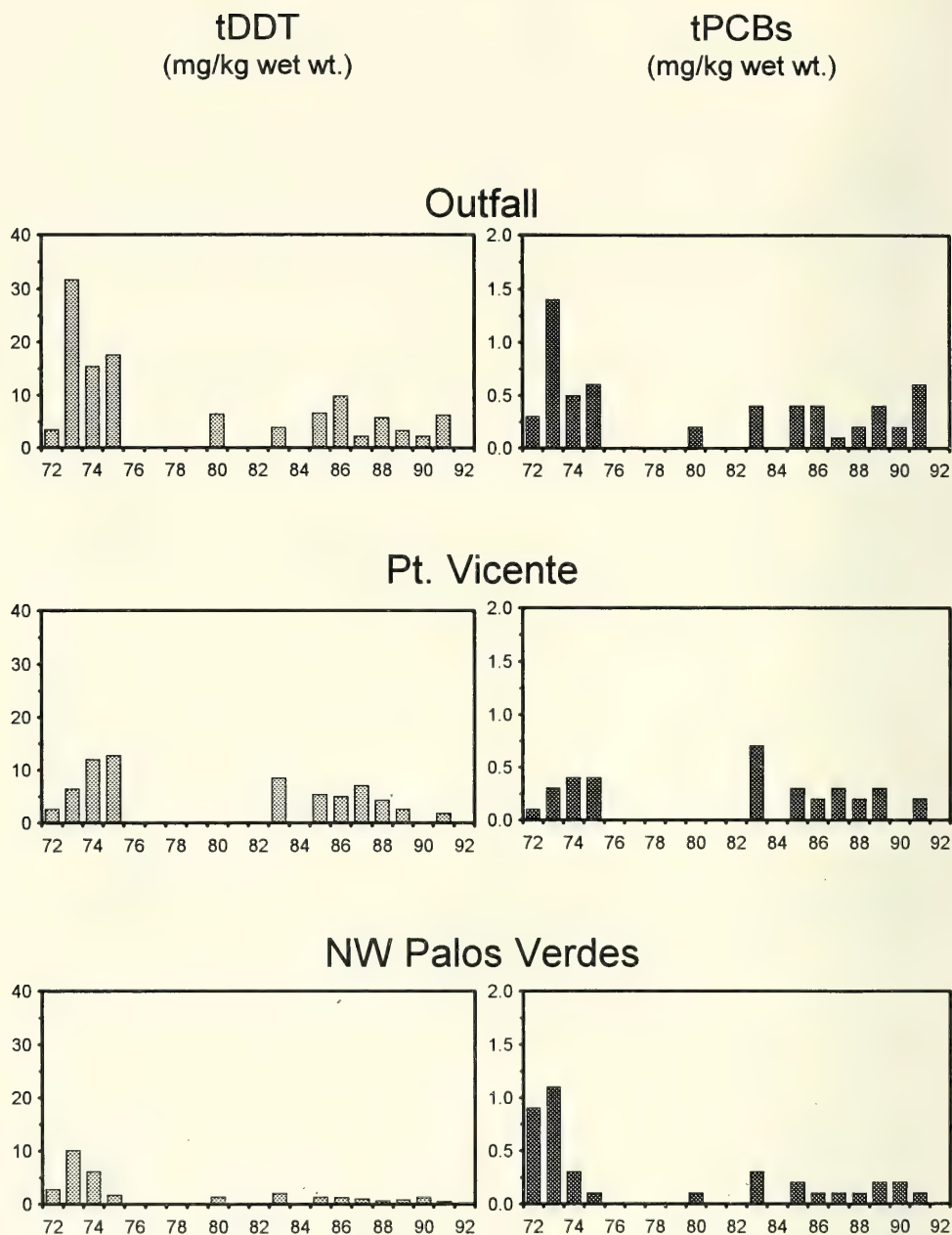


Fig. 15. Fin erosion in Palos Verdes Dover sole taken from 137-m depth, 1972 to 1992. Semiannual surveys 1972 to 1977; quarterly surveys 1978 to 1992.



All fish are 18-21 cm standard length.

tDDT= o,p'- and p,p'- isomers of DDT, DDD, DDE.

PCBs=Aroclor 1242+1254(+Aroclor 1260 from 1988).

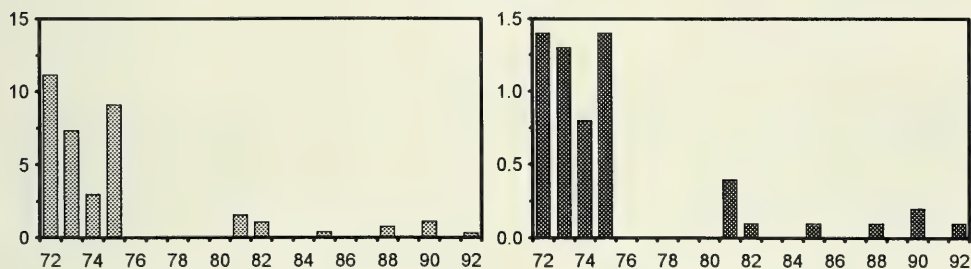
mg/kg wet wt.=ppm ww.

Fig. 16. Median concentrations of DDT (left column) and PCBs in Dover sole muscle tissues, 1972 to 1991. Fish from 61- and 137-m depths at outfall, Point Vicente and northwest Palos Verdes sites.

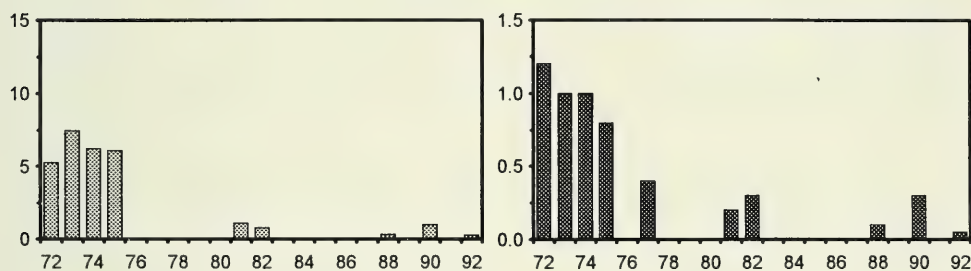
tDDT
(mg/kg wet wt.)

tPCBs
(mg/kg wet wt.)

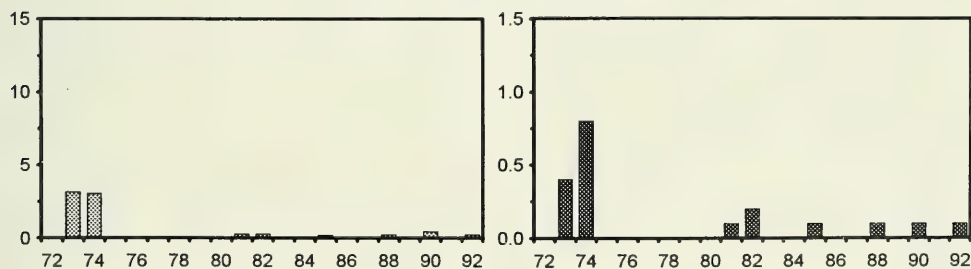
Outfall



Pt. Vicente



NW Palos Verdes



All fish are 24-32 cm standard length.

tDDT= o,p'- and p,p'- isomers of DDT, DDD, DDE.

PCBs=Aroclor 1242+1254(+Aroclor 1260 from 1988).

mg/kg wet wt.=ppm ww.

Fig. 17. Median concentrations of DDT and PCBs in kelp bass muscle tissues, 1972 to 1992. Fish from 6- to 25-m depths at outfall, Point Vicente and northwest Palos Verdes sites.

Kelp bass is an important sportfish, whose populations off Palos Verdes increased in the 1980s with the expanding distribution of kelp (Stull *et al.* 1987). This non-migratory predator lives in shallow waters less than 30-m. It is benthopelagic, often in kelp beds or near rock outcrops, and it preys on cephalopods, worms, crabs and fish. The decrease in DDT and PCB levels was more rapid in kelp bass (Fig. 17) than in Dover sole. Concentrations more or less levelled off in the 1980s.

Discussion

Sediments.—Palos Verdes surface sediment contamination has decreased remarkably over the past two decades, primarily because of declining effluent mass emissions (Stull *et al.* 1986b). Other physical, chemical and biological factors also influenced sediment quality, including sediment resuspension (small or large scale events), burial and bioturbation. Surface sediments are, however, the tip of the iceberg. The major concern today is the partly buried reservoir of historically discharged contaminants preserved in Palos Verdes shelf and slope sediments. Over the half century of disposal, a sediment mound containing contaminants built up. Highest levels of historically deposited contaminants are buried 10 to 25 cm at the 50- to 60-m water depth (Fig. 6). Not only does this partly buried reservoir influence surface sediment quality and sediment dwelling organisms, but it is also available for bioaccumulation up the food chain, including fish and humans.

Benthos.—Among the benthic assemblages, improvements which have occurred over time include the repatriation of species to areas from which they were previously excluded (Stull *et al.* 1986a,c); increased diversity; increased arthropods and echinoderms and fewer molluscs; shared dominance among more species; and decreased opportunists such as *Capitella "capitata."* Aggressive burrowers have become more prevalent: these move subsurface sediments to the surface. Mud or ghost shrimp (Thalassinids such as *Neotrypaea californiensis* and *Acanthaxis spinulicaudus*) are examples of such fossorial groups. Improved sediment quality associated with reduced effluent emissions, stimulated by natural events such as El Niños, storms and biological invasions (Stull *et al.* 1986b,c), probably were important factors in benthic recovery.

Kelp beds.—The flourishing kelp beds on Palos Verdes are significant ecological improvements; these primary producers provide food, habitat, and a nursery area to many fish and invertebrates (Foster *et al.* 1983). Reductions in suspended solids emissions contributed to this recovery, although many other biological and meteorological events play significant roles in controlling kelp populations.

Trawl invertebrates.—Among trawled epibenthic megainvertebrates, the major population changes appear to result from widespread climatic events, notably the 1982 to 1983 El Niño and storms. *Pleuroncodes planipes* is a warm water galatheid crab, partly pelagic and partly demersal. It is normally most abundant west off the southern half of Baja California but is regularly transported to Southern California by the California countercurrent during El Niño events (Radovich 1961; Boyd 1967). The shrimp *Sicyonia ingentis* was also abundant during and following that El Niño. *Portunus xantusii* is a warm water brachyuran crab with a more southern distribution (Garth and Stephenson 1966); it was collected on the inner

shelf nearer the outfalls. On the other hand, *Astropecten verrilli* was less abundant and *Pandalus jordani* disappeared after the 1982 to 1983 El Niño.

Spatial patterns were on a smaller scale, and related foremost to depth zonation, habitat, and wastewater discharge. *Lytechinus pictus* was most abundant on the shelf, and *Pandalus jordani* was common on the upper slope, both near Redondo Canyon. *Sicyonia ingentis* was abundant on the upper slope at outer transects (T0 and T5), while *Pleuroncodes planipes* was common at outfall (T4) and T1 outer shelf and upper slope sites. On the upper slope, *Allocentrotus fragilis* was least abundant at the outfall (T4).

In a multivariate analysis of Southern California monitoring data (1168 trawls, 224 sites, 10 to 915 m, 1971 to 1984), Thompson *et al.* (1983) classified pre-1980 Palos Verdes samples as a unique low diversity assemblage. In the 1980s this unique cluster group declined, and Palos Verdes sites were classified with the normal shelf assemblage for Southern California.

Clearly the diversity and distribution of Palos Verdes epibenthic invertebrates has increased since the 1970s, and improvements in habitat quality are one of many influential environmental variables.

Trawl fish. — Fish populations also fluctuated over the two decades, usually over the entire Palos Verdes study area in response to large scale conditions. Hypotheses can be forwarded as to causal agents, but because of continuing environmental perturbations of variable intensities, frequencies and durations, cause-effect relationships cannot be quantified. Following are a few general observations, which use detailed studies of functional organization of Southern California demersal fish by Allen (1982) to characterize the species habits.

Water temperatures, including El Niño and associated conditions, appear to be a primary determinant of fish catches. Coldwater taxa tended to decline in the 1980s and 1990s, e.g., curlfin sole at 23-m, and rex sole at 137-m. Warm temperate species increased, including California lizardfish (*Synodus lucioceps*), bigmouth sole and fantail sole at 23-m, California tonguefish, hornyhead turbot and bigmouth sole at 61-m, and gulf sanddab at 137-m. Some species were more commonly caught during the major El Niño periods (1973, 1977, 1982 to 1983), including California lizardfish and white seaperch (23-m) and shiner perch and white croaker (61-m). Perhaps they moved out to deeper water. Another important climatic factor is storms and attendant habitat changes; major ones were associated with El Niño in 1982 to 1983 and without in 1988. Following storms, more California lizardfish (23-m), tonguefish (61-m), and slender sole and plainfin midshipman (137-m) were caught.

Habitat quality, and in particular sediment character, appears to correlate with population changes. At the discharge depth (60-m), water column, round fish with swim bladders decreased and bottom living fish increased (Figs. 12 to 14). Bottom fish were common at 23- and 137-m throughout the two decades. Among the species whose populations increased, most bury themselves in sediments during periods of inactivity (an exception is the longspine combfish). Many species which decreased have different habits: white seaperch, stripetail rockfish, splitnose rockfish, and shiner perch are exposed during inactivity, calico rockfish use crevices at times, and white croaker form schools for refuge.

Reproductive modes can influence dispersal, early survival, recruitment and habitat requirements. Fish with pelagic eggs and larvae predominate on Palos

Verdes, e.g., flatfish, white croaker, California lizardfish. Species with internal eggs and pelagic larvae (stripetail, calico and splitnose rockfish), or internal eggs and larvae (white seaperch, shiner perch) were among those which decreased from the 1970s. Some species with demersal eggs and larvae (plainfin midshipman, blackbelly eelpout) and demersal eggs and pelagic larvae (longspine combfish) increased.

Food resources changed between 1972 and 1992. A broader diversity of annelids, molluscs, arthropods and echinoderms became available. Molluscan biomass decreased, and microcrustacea in particular (e.g., gammarids and mysids), became more common. This probably contributed significantly to the successes of California tonguefish, longspine combfish, bigmouth sole, slender sole, and others (e.g., Cross *et al.* 1985). At 23-m, the bottom species which increased tend to ambush water column prey.

The diversity and distribution of Palos Verdes fish assemblages improved from the early 1970s. Species which had been enhanced near the outfalls declined, e.g., shiner perch, curlfin sole, white seaperch, English sole, and Dover sole. Other species have become more prevalent near the discharge, including California halibut, hornyhead turbot, and California tonguefish. A few species such as yellowchin sculpin and longspine combfish are still reduced near the outfall.

Persistent differences in the central Palos Verdes fauna may be due to substrate type (finer and more organic vs coarser or reef substrates), topography (narrow shelf and steep slope, outfall structure, canyon), food resources, and the discharge of treated wastewaters (especially the sediment reservoir of historically deposited trace contaminants).

Fin erosion.—Fin erosion was common in Palos Verdes Dover sole in the early 1970s. The specific cause of this syndrome has never been determined, however, it is thought to be associated with contaminated sediments (e.g., Sherwood and Mearns 1977). With improving environmental conditions this syndrome has disappeared, first at sites distant from the outfall, and later nearer the discharge.

Tissue contaminants.—Although tissue concentrations of DDT and PCBs have decreased markedly since the 1970s, the Palos Verdes shelf biota continue to carry body burdens of these chlorinated hydrocarbons (Smokler *et al.* 1979; Young *et al.* 1988; and Mearns *et al.* 1991). Concentrations tend to be higher nearer the outfall. Sediments carry a reservoir of historically discharged chlorinated hydrocarbons, and are the only significant source of DDT and PCBs to the biota. Current discharge levels of DDT are very near detection limits, and PCBs have not been detected in the effluent for many years.

The greatest concerns off Palos Verdes relate to past discharges of toxic chemicals, and particularly to the partly buried sediment reservoir of bioavailable DDT and PCBs. These chlorinated hydrocarbons pose potential health problems for both marine organisms and their human consumers. California-EPA's Office of Environmental Health Hazards Assessment (OEHHA 1991) analyzed edible muscle tissue from 16 marine fish species at 24 locations for chemical contaminants, and made site specific consumption recommendations which have been incorporated into the California sport fishing regulations (California Dept of Fish and Game 1992). OEHHA recommend that Palos Verdes white croaker not be consumed, and Whites Point sculpin, rockfishes and kelp bass (together) not be consumed at more than one meal every two weeks. Other recommendations apply

to other areas of the Southern California Bight. Sport fishing advisories are posted along the coastline. DDT and PCBs are lipophilic compounds; highest muscle tissue concentrations have been measured in the lipid rich tissues of white croaker (e.g., Gossett *et al.* 1982). The Palos Verdes commercial white croaker fishery was closed in 1991, based on health risk evaluations of the California Dept of Health Services (1990), predecessor agency of Cal-EPA OEHHA. Tissue levels of DDT and PCBs have not decreased substantially since consumption guidelines were released, and sediment contaminants continue to be available.

Conclusions

There is an abundant and diverse flora and fauna off Palos Verdes. Very strong environmental and biological recovery was monitored from 1972 to 1992. Concomitant with reduced discharges of solids and contaminants, the areal extent of surface sediment contamination and organic enrichment decreased. Benthic organisms increased in diversity and range. Kelp beds expanded, and provide important habitat for other marine organisms. Fish species which had been common and associated with wastewater discharge during the 1970s decreased, while others which had been notably absent on Palos Verdes increased in number.

There has been considerable interannual variation in Palos Verdes catches of benthos, demersal fish and epibenthic invertebrates. Only a local perspective of the longterm history can be provided. Fluctuations may be related to climatic factors, sporadic recruitment, prey availability and other unknown or stochastic factors. Nevertheless there have been clear improvement trends in all biological assemblages monitored on Palos Verdes.

The partly buried sediment reservoir of DDT, PCBs, metals and PAHs on the Palos Verdes shelf and slope is a legacy from historic discharges. Continued bioavailability of DDT and PCBs are of particular concern to both the biota and human consumers.

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Changes in Assemblages of Infaunal Organisms Around Wastewater Outfalls in Santa Monica Bay, California

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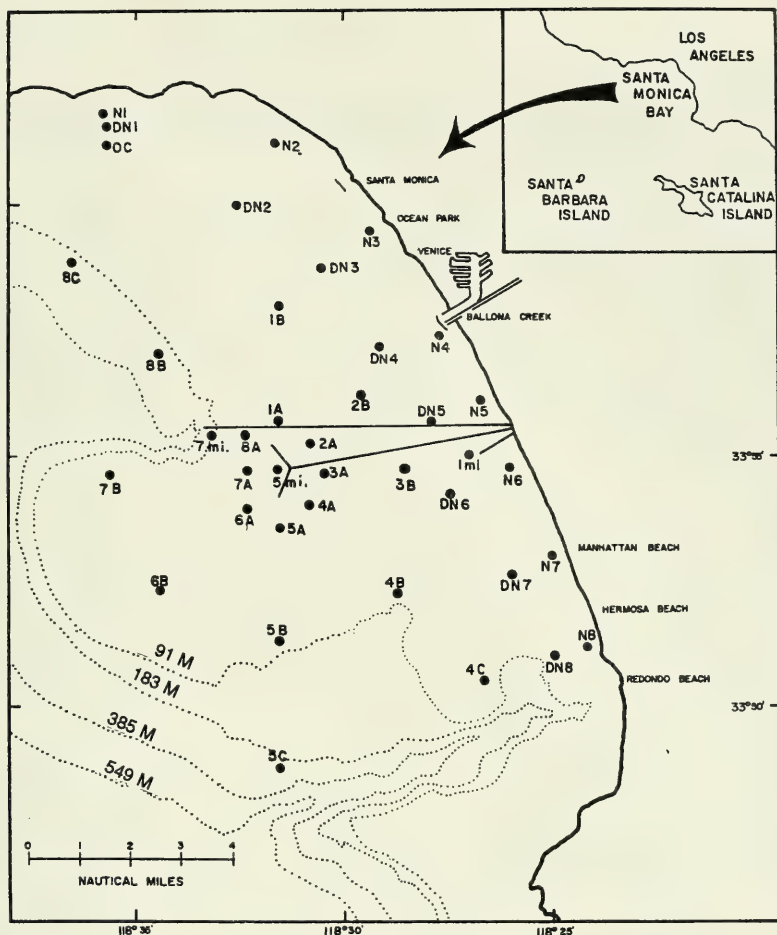
Abstract. — The City of Los Angeles' Hyperion Treatment Plant presently operates two submarine outfalls: the 1-Mile outfall was used until 1959, but now is used only during emergencies; the plant's main outfall, the 5-Mile, presently discharges about $1,211 \times 10^6 \text{ l d}^{-1}$ of mixed primary and secondary effluent at a water depth of 60 m. A third outfall, the now defunct 7-Mile sludge line, operated from 1957-87, discharging about $15 \times 10^6 \text{ l d}^{-1}$ of digested sludge into 100 m of water at the head of the Santa Monica Canyon. Solids discharged from Hyperion into the Bay have been greatly reduced since the mid-1980's; sludge disposal was terminated, and levels of suspended solids in the 5-Mile effluent diminished from peak levels of 155 mg/L in 1985 to historically low levels averaging around 30 mg/L in recent years.

Analyses of ten years of semiannual benthic monitoring data demonstrated that assemblages of benthic organisms near the outfalls have shifted in composition from a polluted condition to one more typical of cleaner reference areas. This trend correlated with reductions of solids discharged from the plant. The infaunal assemblage in the old sludge field has changed from a highly degraded to an early transitional assemblage in terms of species composition and abundance, while those near the 5-Mile outfall have changed from polluted to a more natural assemblage. Continued recovery is expected, but at a slower rate, if the plant maintains its present effluent quality as it moves towards full secondary treatment in 1998.

Wastewater from the City of Los Angeles' metropolitan area has been discharged from the site of the Hyperion Treatment Plant since 1894. During this period, the population of Los Angeles has grown to approximately 4 million people. Consequently, the volume of wastewater and associated solids discharged into Santa Monica Bay from Hyperion increased. In response to escalating populations, the plant has undergone several major changes in how sewage is treated, and where the resulting effluent is discharged into the Bay. Changes have been most notable during the past decade where discharges of solids to the Bay have been dramatically reduced. As a result, assemblages of benthic organisms residing around the submarine outfalls have become much more natural in diversity and abundance.

In this paper, we summarize the history of treatment at Hyperion and its effects on infaunal assemblages in Santa Monica Bay. This summary is based on the

A.



B.

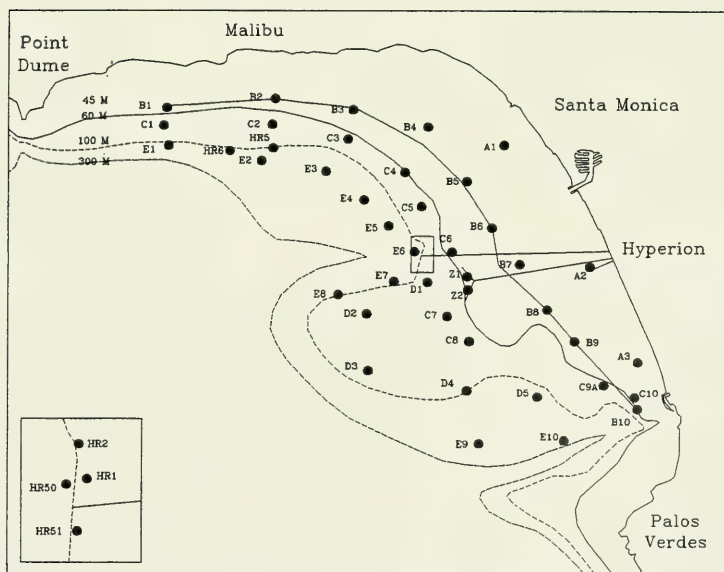


Fig. 1. Benthic sampling stations for the Hyperion marine monitoring program during A) 1972-86, and B) 1987 to present.

results of a decade of semiannual benthic monitoring of sediments. This program is one of many prescribed in the NPDES ocean monitoring program for Hyperion; details of all marine monitoring along with data analyses are presented in annual assessment reports (CLA-EMD 1989, 1990, 1991, 1992, 1993, 1994). Information also is summarized from an early survey by Hartman (1956) on infaunal assemblages throughout the Bay, and the recovery of infaunal populations after abatement of sludge disposal into the Bay from Hyperion (Thompson 1991).

The physical setting—Santa Monica Bay.—Santa Monica Bay is an open coastal embayment located west of the Los Angeles metropolitan area (Figure 1). The Bay is bordered by Point Dume to the northwest and Palos Verdes Point to the south, and encompasses approximately 460 km². The shelf of the Bay is penetrated by two prominent submarine canyons. The Santa Monica Bay canyon is positioned about mid-bay, lying about 11 km offshore from Ballona Creek. Redondo Canyon lies in the southern portion of the Bay, reaching nearly to the shoreline by King Harbor. The bottom habitat of the Bay primarily comprises soft sediments of which sand predominates (Terry *et al.* 1956). Sediments grade from inshore sands to offshore silts along the basin slopes and canyons. This gradient is disrupted by areas of coarse deposits, particularly along the outer shelf area between the Santa Monica and Redondo Beach submarine canyons. This area, termed Short Bank by local fishermen, is characterized by patchy areas of exposed bedrock, rock pinnacles, gravel, and mixed sediments.

Hyperion Treatment Plant.—Sewage effluents have been discharged into Santa Monica Bay from the Hyperion site since 1894. Until 1925, raw sewage was discharged into the surf zone via various small pipes, fouling the beaches in the area. In 1925, a screening facility was built at the site to remove larger solids from the flow of sewage. Also, the 1-Mile submarine outfall was constructed to convey the wastewater further offshore. However, the new outfall had leaks due to construction problems, and as flows to the plant increased, the area of fouled beaches around Hyperion not only persisted, but increased in extent. By 1943, 16 km of beaches around Hyperion were quarantined by the State Health Department based on extensive bacteriological studies by Hyperion Engineers (BSE 1943).

By 1951, construction of the new Hyperion treatment plant was complete along with a new 1-Mile submarine outfall. The new plant was a full secondary treatment facility designed to treat an average flow of 927×10^6 l d⁻¹ using a high rate, activated sludge process. Chlorinated secondary effluent was discharged through the 1-Mile outfall while sludges were digested, dewatered, and made into fertilizer. At this time the beach quarantine was lifted.

By the middle 1950's the decision was made to design and construct longer outfalls. The 1-Mile was to be replaced by a longer liquids outfall to further reduce potential bacterial contamination in inshore recreational waters. Fertilizer produced by the plant was not cost-effective, so the decision was made to discharge digested sludge offshore into deeper areas of the Bay.

A major study of Bay pollution was conducted from 1953–54 by the Allan Hancock Foundation, University of Southern California. Information from this study was used to site the two outfalls. The sludge outfall (the 7-Mile) would reach approximately 11 km offshore, measure 51 cm in diameter, and convey digested sludge into the head of the Santa Monica Canyon at a depth of 91 m. A second

liquids outfall (the 5-Mile) would extend 8 km offshore, measure 3.7 m in diameter, and discharge unchlorinated liquid effluent from a "Y"-shaped diffuser at a depth of 60 m.

Both outfalls were constructed in the late 1950's. The 7-Mile outfall became operational in 1957 and discharged approximately $15 \times 10^6 \text{ l d}^{-1}$ of digested sludge for the next 30 years. The 5-Mile outfall became operational in 1960 and operates today. The older 1-Mile outfall is used only in emergencies whereby chlorinated secondary effluent is discharged.

The quality of effluent from Hyperion diminished as flows increased. Correspondingly, the proportion of primary:secondary treatment increased because the plant was capable of providing secondary treatment only to $379 \times 10^6 \text{ l d}^{-1}$ of flow. Flows from the 5-Mile increased from $988 \times 10^6 \text{ l d}^{-1}$ in 1960 to a peak of $1,571 \times 10^6 \text{ l d}^{-1}$ in 1985. During this year, effluent solids reached a historic high of 155 mg/l with a removal efficiency of 35.3%.

During the 1980's, several key events occurred to greatly reduce solids discharged into the Bay from Hyperion. Sludge combustion and handling facilities became operational, so sludge disposal from the 7-Mile outfall was stopped in 1987. The City made the commitment to rebuild Hyperion as a full secondary treatment facility by 1998. In 1986, the Hyperion Interim Improvements Project was initiated to enhance the quality of effluent during the construction of full secondary treatment facilities. This project, coupled with reduced flows to the plant from water conservation and drought conditions ($1,188 \times 10^6 \text{ l d}^{-1}$ during 1992–93), resulted in a marked improvement in the quality of effluent. Several effluent constituents reached their lowest levels in the history of the plant (Figure 2). For example, suspended solids reached record lows during 1992–93, averaging 33 mg/l with an average removal efficiency of 90.8%.

Sediment contamination in the bay.—Elevated levels of various metals remain concentrated in certain areas of the Bay, despite the reduction in mass emissions from Hyperion. As reported in CLA-EMD (1994), elevated levels of sulfides and several metals (e.g. cadmium, copper, silver) were concentrated in surface sediments around both the 5-Mile outfall and in the old sludge field adjacent the 7-Mile outfall (Table 1). These contaminants were up to one order of magnitude greater around the 5-Mile outfall compared to the overall bay wide average for these contaminants, and one to two orders of magnitude greater in the old sludge field.

Chlorinated hydrocarbons are the organic pollutants of concern in the Bay. Concentrations of PCBs (mainly PCB 1254) are concentrated mainly around the non-operating 7-Mile outfall, but have diminished several fold since termination of sludge discharge (Thompson 1991). Breakdown derivatives of the pesticide DDT (mainly p,p'-DDE) are found mainly in the southern portions of the Bay adjacent the contaminated Palos Verdes Shelf. Concentrations of this organic pollutant essentially have remained the same since 1987 (CLA-EMD 1989 through 1994).

Infaunal assemblages.—Changes in the physical and chemical nature of benthic habitats most affect the infauna, small-bodied (generally $<1.0 \text{ mm}$ in any one dimension) invertebrates living in or on the sediment habitat. Infaunal assemblages play a key role in the dynamics of benthic ecosystems through their bur-

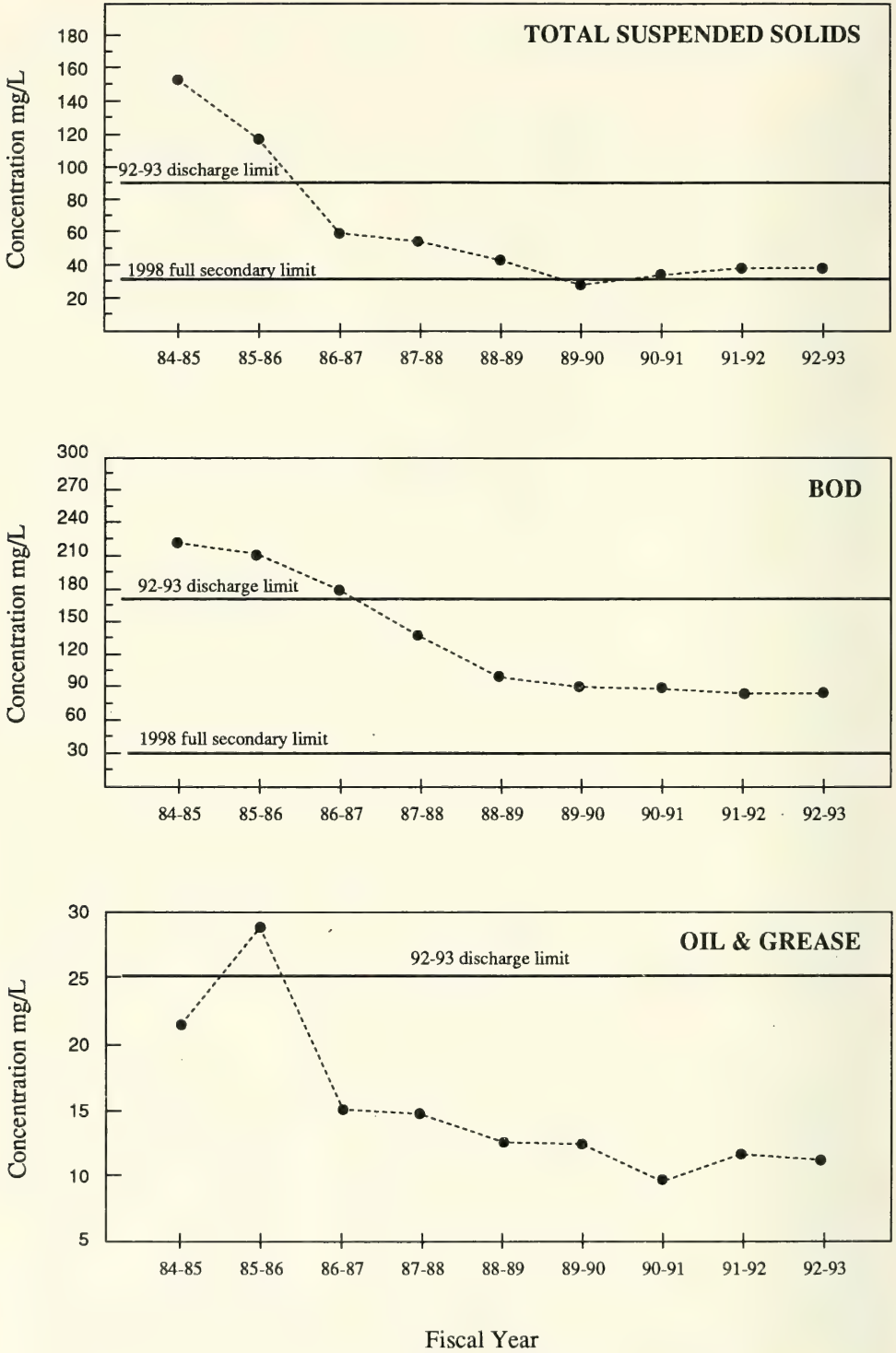


Fig. 2. Average concentrations of total suspended solids, oil and grease, and biological oxygen demand in 5-Mile effluent from 1984-85 through 1992-93.

Table 1. Levels of sediment contaminants at the 5-7-Miles outfalls in Santa Monica Bay, 1988-1992. Units = mg/kg for metals, oil and grease; µg/kg for organics; values normalized against fine grained (=silt + clay) sediments.

Contaminant	5-Mile					7-Mile					Santa Monica Bay Average (SD) ^a				
	1988	1989	1990	1991	1992	1988	1989	1990	1991	1992	1988	1989	1990	1991	1992
As	7.84	7.65	10.5	9.40	7.68	21.8	24.6	35.3	26.3	26.8	15.0	14.4	16.1	13.3	10.8
Be	0.60	0.36	0.57	0.74	0.46	0.56	0.75	0.64	0.57	0.69	1.26	1.08	1.06	1.06	0.86
Cd	6.2	4.5	5.5	4.6	5.40	47.9	54.8	45.7	36.4	32.5	3.94	4.05	3.14	2.95	5.54
Cr	135	108	129	109	118	431	681	408	325	357	117	177	166	148	168
Cu	98	86	95	79	95	752	844	727	542	536	107	103	88.4	86	134
Hg	0.7	0.5	0.6	0.37	1.09	5.1	3.5	4.0	2.17	6.50	0.80	0.69	0.65	0.48	0.87
Pb	60	39	31	25	0	23	242	192	169	167	85	75.3	44.6	40	40.7
Ni	51	34	28	30	25.4	131	131	89	71.9	74.2	68	64.3	38.2	37.3	43.8
Ag	10.4	8.2	9.2	5.88	7.75	61.2	49.7	71.9	53.3	14.8	7.91	6.89	6.75	5.99	3.31
Se	ND	0.67	0.62	0.67	0.18	5.56	4.40	5.45	3.62	2.93	0.2	0.84	1.03	0.89	0.71
Tl	ND	ND	ND	ND	0.51	ND	ND	ND	0.83	0.75	12	ND	0.20	0.13	0.77
Zn	169	144	150	146	154	121	1099	838	664	782	190	90	167	155	232
Sulfide	0.1*	0.7*	0.6*	0.5*	0.5*	6.0*	3.0*	20.3*	89*	42*	NA	0.1*	0.7*	2.8*	0.6*
Toluene	20.8	52.2	ND	1.49	ND	77.8	20.3	1.56	3.06	1.78	13.9	13.4	4.32	1.12	1.83
Benzene	6.9	ND	8.15	0.89	ND	16.8	ND	7.05	1.87	0.82	5.87	1.88	3.20	0.65	0.14
Ethyl benzene	4.0	ND	16.3	ND	ND	24.4	ND	ND	2.82	ND	3.72	0.76	1.70	0.18	ND
B-BHC	300	365	ND	ND	ND	1901**	1470	ND	ND	ND	8.69	178	ND	213	ND
DDT	NA	72.5	124	80.1	105	NA	334	199	820	310	190	230	223	416	295
PCB	113	ND	265	107	167	108	98	171	1830	682	84.1	26.6	74.3	250	304

* = mg/L

** = summer 1989 survey data; 1988 data omitted due to analytical error.

* = stations with < 20%. Silt and clay were excluded.

ND = not detected.

NA = not available.

SD = standard deviation.

rowing and feeding habits (bioturbation), stabilization of sediments through tube-building, input of larvae into pelagic and benthic systems, and trophic dynamics as both predators and prey.

Because infaunal organisms are relatively sedentary, they can not readily migrate from a source of contamination. Pollution-sensitive species will die, or their larvae may not settle (or grow) depending on the nature and level of contamination. As sensitive species diminish in a stressed area, and more pollution-tolerant, opportunistic species flourish, a biotic gradient will develop from polluted to unpolluted areas reflected by the species present and their relative abundance (Pearson and Rosenberg 1978, Gray 1989, Weston 1990). Key species therefore can be used as indicators of environmental quality (Reish 1984). Interpretable patterns derived from measurements of an altered assemblage, coupled with the relative ease of sampling, render this group ideal for assessing the effects of benthic pollution (Bilyard 1987), particularly around point sources of organic enrichment like ocean wastewater outfalls. For these reasons, infaunal assemblages in Santa Monica Bay have been extensively monitored to assess impacts of effluent disposal on their populations.

The Hartman survey (1952–56).—Infaunal populations were first extensively surveyed in Santa Monica Bay by Hartman (1956). Approximately 150 sediment samples were collected between 1952 through 1956 to characterize infaunal assemblages around the 1-Mile outfall and the proposed discharge areas of the future 5- and 7-Mile outfalls then under design. The investigation generally was qualitative in that emphasis was placed on describing associations of species, particularly polychaeteous annelids.

Hartman subjectively divided the area radiating away from the 1-Mile outfall into four zones (Figure 3). The area termed Limited-Pollution-Fauna was dominated by polychaetes, particularly *Nephtys caecoides*, *Nothria elegans*, *Diopatra ornata*, and *Nereis procera*. Echinoderms, mainly *Amphiodia* spp., mollusks, and smaller crustacea were scarce or absent. Numbers of species and abundance increased in the next area, termed Pollution-Tolerant-Fauna, where common species included the polychaetes *Glycera americana*, *Marphysa* nr. *conferta*, *Nereis procera*, and *Pectinaria californiensis*, and increased numbers of some mollusks, crustaceans, ophiuroids, and the asteroid *Astropecten* sp. In Hartman's third zone, the Limited-Enriched-Fauna, the infaunal assemblage was "... considered limited for lacking some species known to occur in similar areas that are not polluted," but enriched because of the increased diversity and unusually high abundance of species like the polychaetes *P. californiensis*, *Onuphis nebulosa*, and the ophiuroids *Amphiodia* spp. The final zone, termed Unlimited-Enriched Fauna, was rich in species, but lacked the abundance found in the previous zone.

Hyperion infaunal monitoring program (1972–Present).—Monitoring of infaunal assemblages around Hyperion's outfalls by the City of Los Angeles began in 1972 with the first NPDES permit issued to the plant, and continues today. The primary goal of this program is to assess spatial and temporal changes in assemblages of infaunal organisms resulting from effluent discharged from Hyperion's outfalls. Patterns in species composition and abundance are compared with Pearson and Rosenberg's (1978) predicted effects of organic enrichment on infaunal communities whereby four zones can exist:

1. a Degraded zone nearly devoid of infauna;

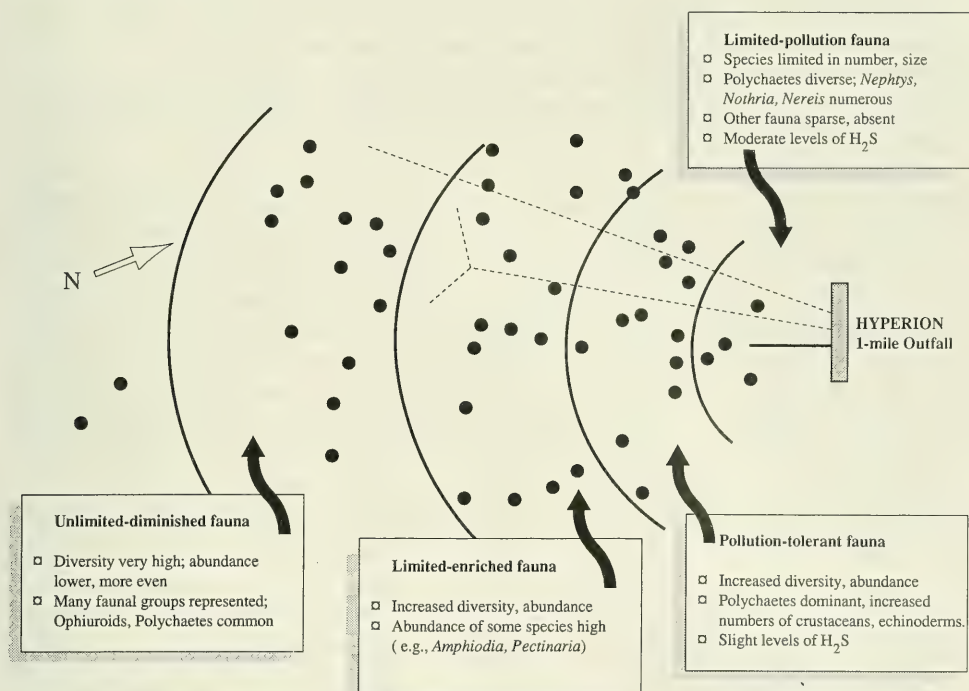


Fig. 3. Faunal zones established around the 1-Mile outfall by Hartman (1956). The dashed lines indicate positions of the future 7- and 5-Mile outfalls; dots indicate Hartman's sampling sites.

2. a Polluted zone of low diversity, but high biomass due to populations of opportunistic species;
3. a Transition zone where diversity and abundance are high owing to a mix of opportunistic and natural occurring populations; and,
4. a Normal or unaffected zone hosting a natural assemblage of organisms.

Methods

Station locations.—Sampling locations of infaunal populations have changed since initiation of the program. The initial station array generally was based on a rosette pattern of 31 stations centered around the 5-Mile outfall (Figure 1), but was changed in 1987 to 39 stations positioned along the 18, 45, 60, 80, and 150 m depth contours (CLA-EMD 1989). Seven new stations were added to the program in 1990. One southern 80 m site (D5) was located in an area of elevated silt, and six deeper stations (HR sites) were positioned in 100 m of water from the terminus of the 7-Mile outfall to locations offshore from the Malibu shelf. These HR sites were used during a special four year study (1986–90) by the Southern California Coastal Water Research Project (SCCWRP) to document recovery of the benthic community around the 7-Mile outfall after termination of sludge disposal (Thompson 1991).

Sampling.—Sampling frequencies and methods have remained constant since implementation of the program in 1972. Sediments are collected semiannually each summer and winter using a modified Van Veen grab (Word 1976) that

samples an approximate area of 0.1 m². Single grabs are collected at each station except during summer collections where five replicates are collected at seven sites along the 60 m contour. All grabs are washed through a 1 mm screen, relaxed in 0.2% propylene phenoxytol, preserved in 10% solution of sea-water formalin, then transferred 48 hrs later to 70% ethanol for storage and processing.

All individuals sorted from samples are identified to species or the lowest possible taxon. Taxonomic consistency is maintained by comparing identifications with laboratory voucher collections, or sending problem taxa to experts with the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT).

Data analyses.—Spatial and temporal patterns for infaunal assemblages are determined using uni- and multivariate techniques. Prior to analyses, each survey data set is taxonomically standardized with previous sets, and added to a master data file. This file contains survey data from 1983 to present. The following community parameters are calculated for each set: total number of species, total number of individuals, biomass, Shannon-Wiener diversity (H'), evenness (J'), and the Infaunal Trophic Index developed by Word (1979). Classification and ordination of each survey data set are performed after methods detailed in Smith *et al.* (1988).

Results and Discussion

Present Infaunal Assemblages (Based on Summer, 1992 Survey)

Santa Monica Bay supports a rich diversity of species due to the heterogenous nature of its benthic habitats. To date, approximately 2,400 infaunal species have been recorded during Hyperion benthic surveys. During the summer survey of 1992, a total of 32,681 individuals were collected representing 625 taxa (CLAMD 1994). Along the 60 m depth contour, the discharge depth of the 5-Mile outfall, an average of 87 species and 444 individuals were collected per grab (Table 2). Biomass varied throughout the Bay with highest values in deeper water due to the presence of large echinoderms or mollusks. The mean community parameters along the 60 m contour (Tab. 2) fell within the limits of the same parameters measured at reference sites in southern California shelf habitats (Thompson *et al.* 1992). The ITI index, used as a pollution index (Bascom *et al.* 1978), averaged 76.9 among all stations, indicating normal conditions throughout most of the Bay. Classification of summer infaunal data resulted in seven groups of stations (Figure 4) and species (Table 3). Sites mainly clustered along depth contours, but two outfall groups were formed. The 5-Mile outfall site-group was characterized by the polychaetes *Aphelochaeta* sp., *Acmira catherinae*, *Mediomastus* spp. and *Capitella capitata*, and the ostracod *Euphilomedes carcharodonta*. The last two species are pollution-tolerant, and can form large populations in organically enriched sediments. The 7-Mile outfall group was characterized by abundances of many pollution tolerant species like the polychaete *Pectinaria californiensis* and the bivalves *Tellina carpenteri*, *Parvilucina tenuisculpta* and *Axinopsida serricata*. A variety of other species occurred at both outfalls, demonstrating that these areas had a mix of pollution-tolerant and normal populations. Using the Pearson-Rosenberg model, assemblages at both outfall areas could be classified as transitional—early transitional for the 7-Mile, and late transitional to nearly normal around the 5-Mile.

Conspicuously absent from the outfall sites was the ophiuroid *Amphiodia urtica*,

Table 2. Community parameters (per 0.1 m²) measured during the Hyperion summer survey, 1992. Included are mean values from the 1990 SCCWRP reference Site Survey (Thompson et al. 1992).

Site	No. of species	Total abundance	Biomass (g)	Shannon-Wiener Diversity	Evenness	ITI
A1	131	570	7.16	4.20	0.86	81
A2	62	181	1.46	3.75	0.91	68
A3	87	486	5.34	3.53	0.79	75
B1	81	548	12.50	2.79	0.64	88
B2	97	548	9.02	3.15	0.69	88
B3	99	720	6.03	3.34	0.73	87
B4	89	500	10.72	2.89	0.64	91
B5	102	526	6.24	3.44	0.74	90
B6	92	479	7.47	3.44	0.76	88
B7	109	525	9.19	3.73	0.80	87
B8	102	454	5.20	3.41	0.74	75
B9	96	389	7.63	3.88	0.85	81
B10	89	332	5.71	3.98	0.89	81
C1	82	713	12.17	2.42	0.55	90
C2	51	520	7.71	1.84	0.47	92
C3	62	372	6.32	2.70	0.66	91
C4	123	485	6.40	4.05	0.84	79
C5	143	715	7.43	3.97	0.80	76
C6	77	549	7.84	3.28	0.75	67
C7	100	430	5.01	3.92	0.85	73
C8	104	381	7.50	3.92	0.84	74
C9a	108	382	10.47	4.04	0.86	82
C10	85	346	7.62	3.84	0.86	80
D1	88	386	4.90	3.27	0.73	58
D2	53	168	3.44	2.72	0.69	73
D3	87	318	3.09	3.65	0.82	73
D4	131	643	13.91	3.85	0.79	74
D5	84	492	4.57	3.05	0.69	85
E1	59	181	12.71	3.05	0.75	90
E2	64	258	8.24	3.43	0.82	79
E3	57	139	4.90	3.59	0.89	75
E4	38	213	6.10	2.43	0.67	67
E5	73	577	31.11	2.83	0.66	57
E6	30	441	22.16	2.22	0.65	52
E7	77	307	4.16	3.54	0.82	61
E8	54	130	5.70	3.51	0.88	78
E9	47	127	32.61	3.08	0.80	70
E10	56	153	4.16	3.36	0.83	70
HR1	54	660	19.41	2.78	0.70	62
HR2	93	715	8.19	3.25	0.72	67
HR5	61	274	4.01	2.80	0.68	88
HR6	61	348	4.08	2.99	0.73	87
HR50	37	795	17.60	1.92	0.53	61
HR51	35	260	14.26	2.40	0.67	56
Z1	64	396	4.46	3.44	0.83	66
Z2	75	479	9.62	3.50	0.81	53
SMB 60-m mean	88	444	7.5	3.49	0.76	77.8
95% CL	54-121	306-592	2.9-12.1	2.61-4.13	0.63-0.89	65.3-90.3
SMB 150-m mean	52	298	13.7	2.94	0.74	68.0
95% CM	37-67	91-506	3.4-24.0	2.36-3.52	0.63-0.85	56.8-79.2
Ref 60-m mean*	87	410	13.2	3.40	0.77	NA
95% CM	66.9-107.1	347.1-471.9	0-28.0	2.9-3.9	0.69-0.85	
Ref 105-m mean	61.6	245.4	7.8	3.32	0.81	NA
95% CL	50.6-72.6	203.2-287.6	4.7-10.9	3.06-3.58	0.76-0.86	

*Modified from Thompson et al., 1992.

Table 3. Two-way table of species- and site-groups, summer 1992. Values are mean species abundance for each site-group. Each number in bold type indicates site-group with highest abundance for each species.

Species-group	Tax-on	Site-group						
		1	2	3	4	5	6	7
1 <i>Lumbrineris limnicola</i>	P	29.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Crepidula dorsata</i>	M	20.7	0.0	0.0	0.0	0.0	0.0	0.0
<i>Hornellia occidentalis</i>	C	18.0	0.8	0.0	0.0	0.0	0.0	0.0
<i>Exogone lourei</i>	P	14.3	0.8	0.0	3.4	3.9	0.0	0.4
<i>Photis</i> spp.	C	13.7	0.9	0.8	4.8	0.5	0.0	0.4
2 <i>Myriochele</i> sp. M (SCAMIT)	P	0.0	16.3	0.7	9.4	0.4	0.0	0.0
<i>Ampelisca brevisimulata</i>	C	0.7	13.7	0.0	3.9	0.0	10.0	0.0
3 <i>Amphiodia urtica</i>	E	0.3	118.2	127.0	11.8	15.9	0.0	0.4
Amphiuridae	E	0.0	47.1	47.7	4.9	7.5	2.3	0.4
<i>Rhepoxynius bicuspidatus</i>	C	0.0	6.2	11.0	0.0	0.5	0.0	0.0
4 <i>Spiophanes missionensis</i>	P	7.0	30.7	41.8	54.9	7.4	4.3	6.0
<i>Caecum crebricinctum</i>	M	12.0	0.0	0.0	19.8	0.0	0.0	0.0
<i>Lumbrineris</i> sp. Group 1	P	0.7	3.4	5.5	11.5	1.9	5.0	6.2
5 <i>Spiophanes fimbriata</i>	P	0.0	0.0	0.0	0.0	10.0	0.0	1.6
6 <i>Aphelocheata</i> sp. C (SCAMIT)	P	0.0	0.2	0.5	3.9	0.9	54.7	3.8
<i>Acmira catherinae</i>	P	0.0	8.9	0.3	3.1	0.0	43.0	0.0
<i>Mediomastus</i> spp.	P	8.0	4.2	4.0	9.0	6.5	36.3	3.4
<i>Euphilomedes carcharodonta</i>	C	0.7	9.5	2.3	5.9	0.0	33.3	7.2
<i>Prionospio</i> sp. A (SCAMIT)	P	1.3	8.5	6.5	18.3	1.8	25.3	8.0
<i>Capitella capitata</i>	P	0.0	0.1	0.0	0.6	0.0	17.7	0.2
<i>Siphonosoma ingens</i>	S	0.0	2.9	0.3	3.3	0.1	13.7	0.0
<i>Macoma</i> sp. (juv.)	M	0.0	2.9	0.3	3.3	0.1	12.3	0.0
7 <i>Pectinaria californiensis</i>	P	0.0	5.3	1.0	14.3	4.1	9.7	135.8
<i>Axinopsida serricata</i>	M	0.0	5.3	2.2	45.3	19.3	23.3	86.8
<i>Parvilucina tenuisculpta</i>	M	0.0	2.1	2.0	32.1	11.8	22.0	76.6
<i>Acila castrensis</i>	M	0.0	0.0	0.0	1.0	11.4	0.0	41.8
<i>Tellina carpenteri</i>	M	0.0	4.5	0.8	10.0	1.8	17.3	33.8
<i>Euphilomedes producta</i>	C	0.0	0.4	8.5	4.3	0.6	3.0	25.8
<i>Tellina</i> sp. A (SCAMIT)	M	0.0	0.1	0.0	1.4	0.3	0.3	10.6

P = polychaete, M = mollusk, C = crustacean, E = echinoderm, S = Sipunculid.

a key indicator species of normal shelf habitats in southern California (Anderson *et al.* 1993, Thompson 1992). This species was abundant in site-groups away from the outfall areas (Table 3).

Ordination analyses resulted in five axes, with the first three accounting for 82.8% of variation in the infaunal data (Axis 1 = 42.6%, Axis 2 = 25.3%, Axis 3 = 14.9%). These three axes were related with various sediment chemical and physical parameters, measured at the time of sampling, using stepwise, multiple regression. Axis 1 correlated only with depth ($R^2 = 0.92$), indicating that this parameter strongly influenced infaunal assemblages in the Bay. The association of changing benthic communities with water depth offshore southern California has been well documented (see Thompson *et al.* 1993). Axes 2 and 3 formed weaker relationships with sediment contaminants found around the outfalls and levels of silt (R^2 for Axis 2 = 0.67, for Axis 3 = 0.62).

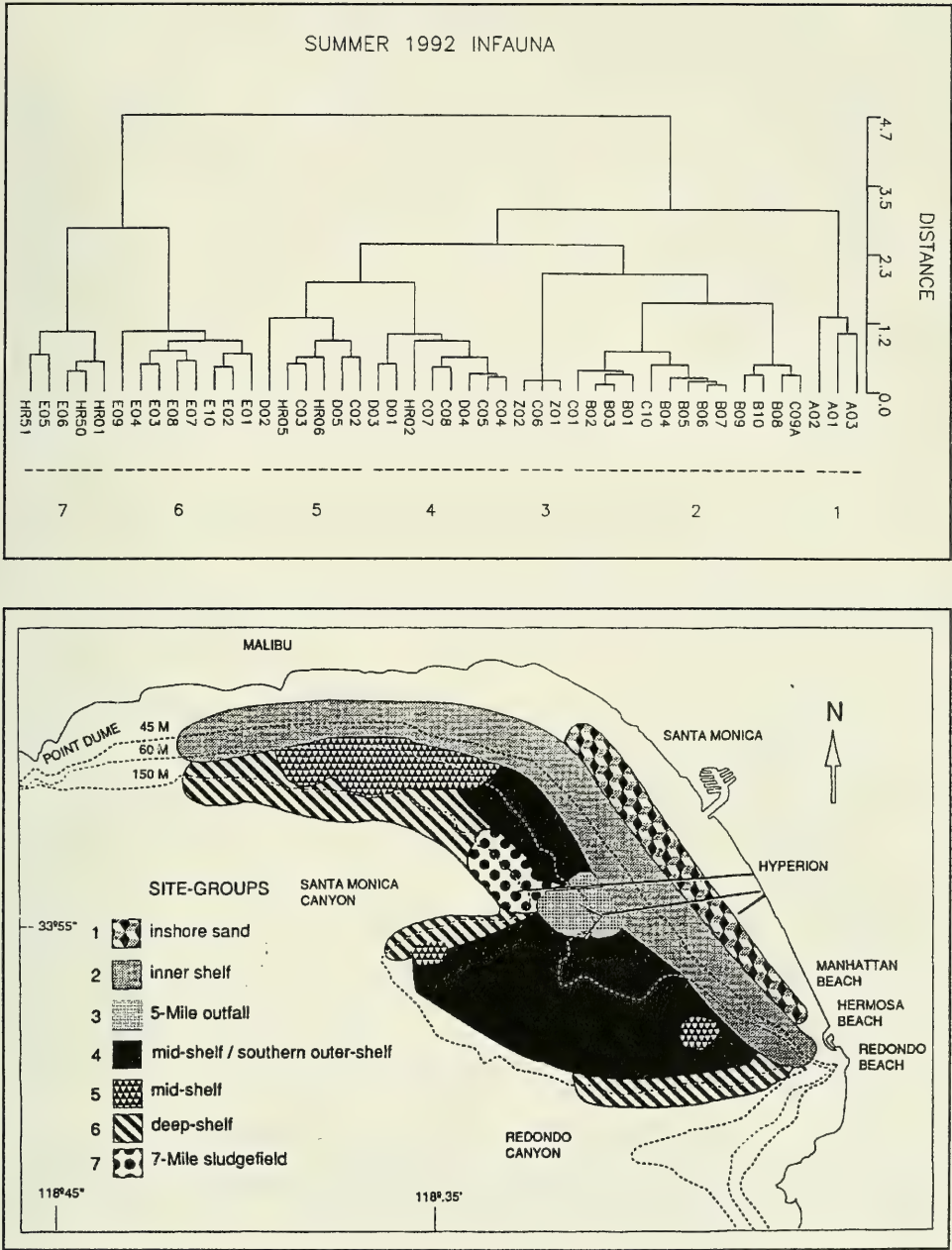


Fig. 4. Results of classification analysis on infaunal data collected during summer, 1992.

Infaunal trends around the Hyperion outfalls.—The composition of infaunal communities around Hyperion’s 7- and 5-Mile outfall system has changed markedly over the past two decades owing to changes in solids discharged from the plant. As shown in Fig. 5a, mass emissions from Hyperion peaked in 1985 then fell to historically low levels by 1990. Corresponding with this trend was a similar

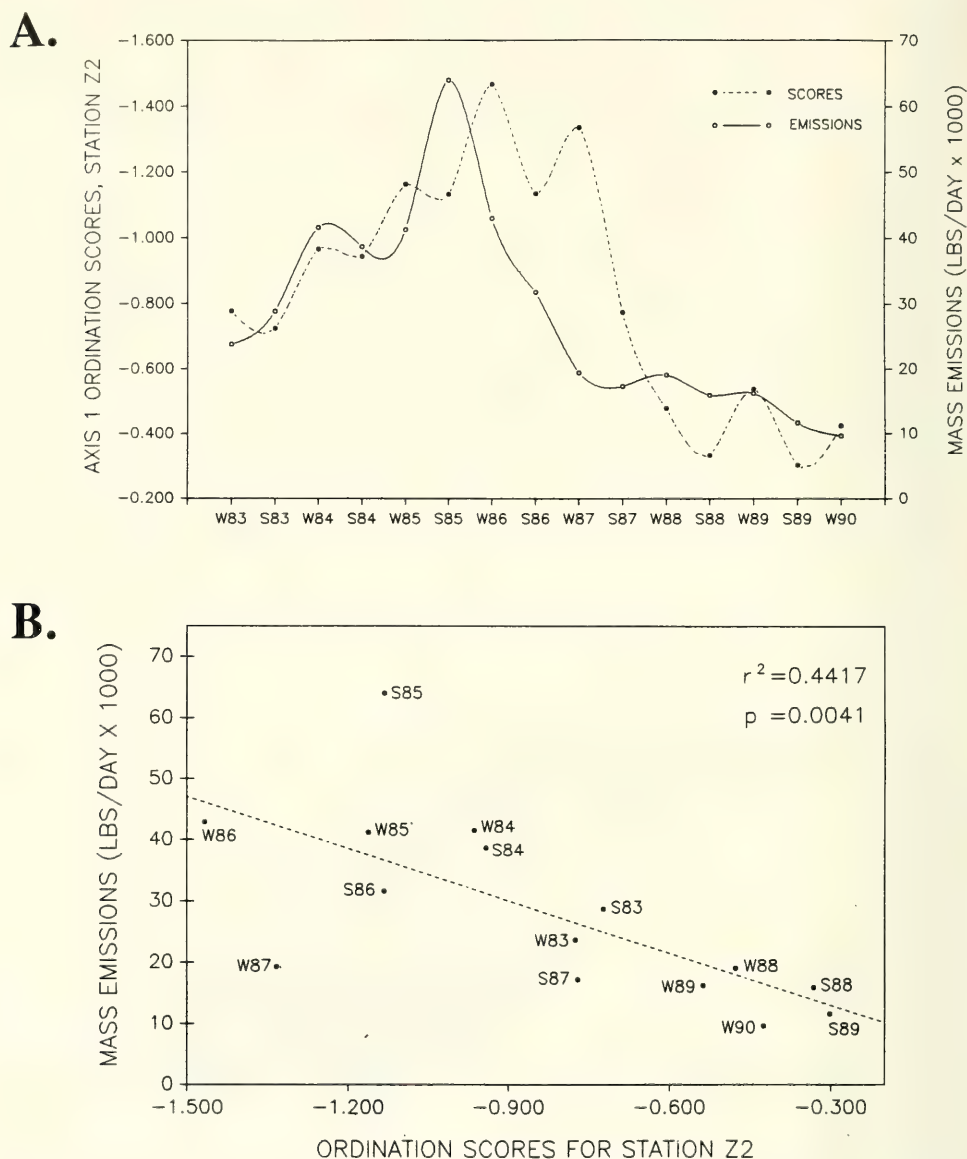


Fig. 5. Relation between mass emissions and Axis 1 ordination scores for Station Z2 positioned at the 5-Mile outfall: **A)** trend from winter 1983 to winter 1990; **B)** correlation between mass emissions and ordination scores for Station Z2 over time (from CLA-EMD 1990).

pattern displayed by ordination scores from the 5-Mile outfall site (Station Z2). Scores were generated from an analysis of a 60 m infaunal data set collected over this period (Figure 5). By selecting data only from sites along the 60 m depth contour, (discharge depth of the 5-Mile outfall), depth was factored out so that the first extracted ordination axis mainly represented a gradient of outfall effects. One end of this gradient represented natural infaunal assemblages expected in a normal reference area, while the other end represented degraded assemblages typical of organically enriched areas.

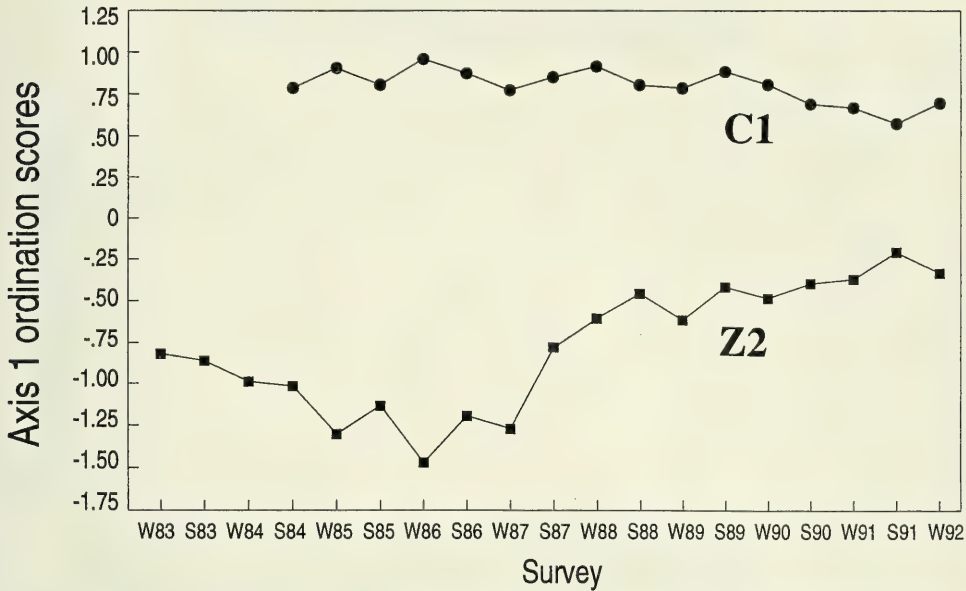


Fig. 6. Axis 1 ordination scores for 5-Mile outfall station Z2 and reference station C1 located in 60 m of water on the Malibu shelf.

Scores from Station Z2 were significantly correlated with mass emissions ($p = 0.004$) but the low R^2 (0.44) indicated that the relationship was weak. This result indicated that changes in the infaunal community lagged behind the trend of diminished solids as abundances of opportunistic species fell, and the outfall assemblage became more natural in species composition and abundance.

Similar to the analysis performed above, ordination scores from the 5-Mile outfall (Station Z2) and the 60 m Malibu reference site (Station C1) were compared over time from 1983 through 1992 (Figure 6). The assemblage at Station Z2 reached the lowest point of the gradient in winter 1986, but then increased towards the reference site end of the gradient.

Thompson (1992) performed a similar ordination analyses of infaunal data collected from the area of the 7-Mile sludge outfall to document the rate of recovery after termination of sludge disposal in 1987 (Figure 7). The trend of ordination scores over time indicated that the highly degraded assemblage present prior to termination displayed initial rapid recovery to more natural conditions, but the rate of recovery had slowed by 1990. Based on regression models, Thompson predicted that assemblages in the sludge field would reach reference site conditions by 2002.

Species composition and abundance changed markedly around the outfalls as demonstrated by the ordination studies described above. As the outfall areas recovered, key indicator species of degraded, polluted, and transitional assemblages reached maximum abundances, then declined.

Trends of some of these species are best described by following recovery around the 7-Mile sludge line (Thompson 1991). Prior to termination, an average of six species existed in the sulfide rich sediments. The most common species was the polychaete *Ophryotrocha* sp. C. After termination of sludge disposal in 1987, the

INFAUNAL ORDINATION

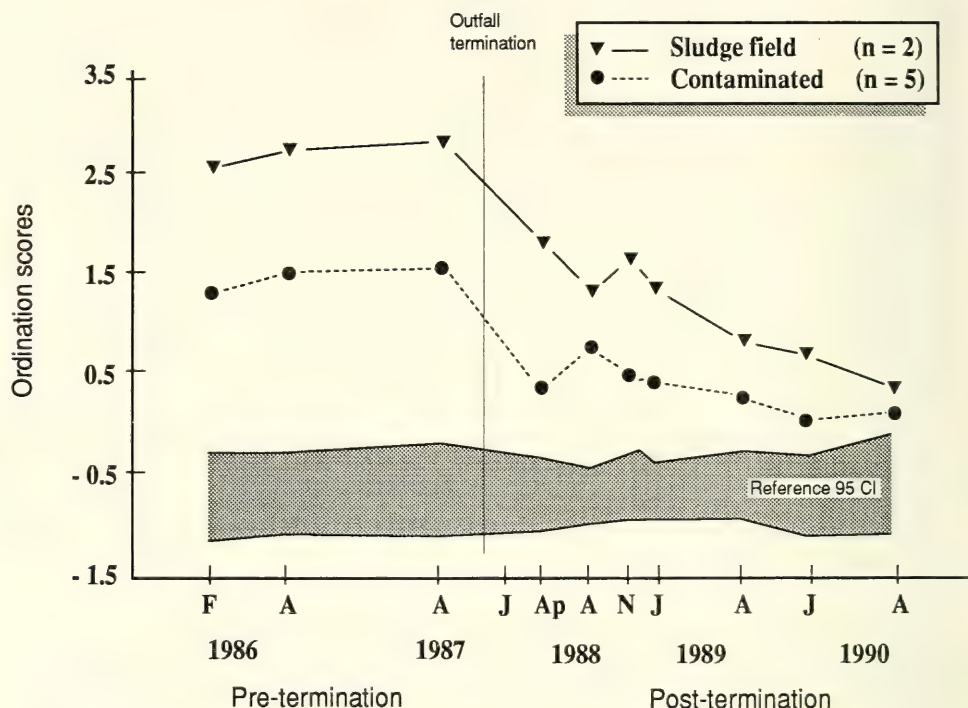


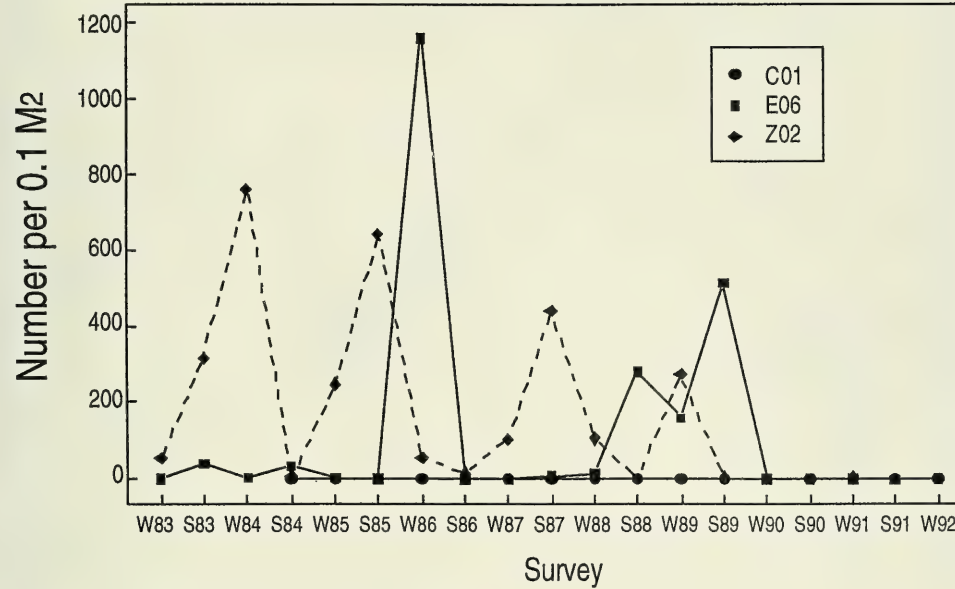
Fig. 7. Ordination scores of sites sampled from 1986 through 1990 during the sludge termination study by SCCWRP (from Thompson 1991); n = number of stations in strata denoted by symbols.

abundance of *Ophryotrocha* sp. C increased by an order of magnitude, then declined to almost zero by August, 1990. The polychaete *Capitella capitata*, an indicator of polluted conditions (Reish 1984), existed in low abundance around the outfall during sludge disposal, but became the most abundant species there within a year after termination (Fig. 8a). In Fig. 8a, the peak of abundance during the winter of 1986 resulted when, through a navigational error, the benthic grab sample was collected on the steep side of the canyon rather than within the sludge field; instead of sampling a degraded assemblage at the end of the pipe, a polluted zone dominated by opportunistic species like *C. capitata* was sampled. By 1990, *C. capitata* was nearly absent in the old sludge field. As populations of *C. capitata* declined, the polychaete *Pectinaria californiensis* became abundant and remains so today (Fig. 8b).

At present, an average of about 50 species inhabit the old sludge field representing a mix of both opportunistic and normal populations. Thompson (1991: p 179) suggested that this recovery process has been driven by "a combination of erosion by sediment resuspension and transport down the canyon, and burial by clean shelf sediments." These processes have enabled more sensitive species to inhabit the cleaner sediments, and bioturbation further mixes and dilutes the deeper sludge deposits.

A.

Capitella capitata



B.

Pectinaria californiensis

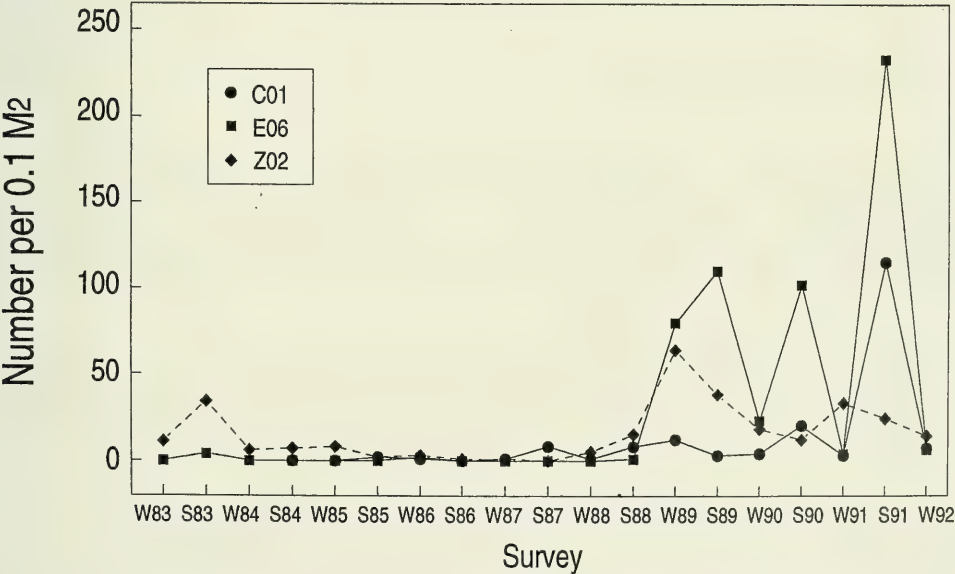


Fig. 8. Abundance of A) *Capitella capitata* and B) *Pectinaria californiensis* from winter 1983 through winter 1992 at the 5-Mile outfall (Station Z2), 7-Mile outfall (Station E6), and reference area (Station C1) on the Malibu shelf.

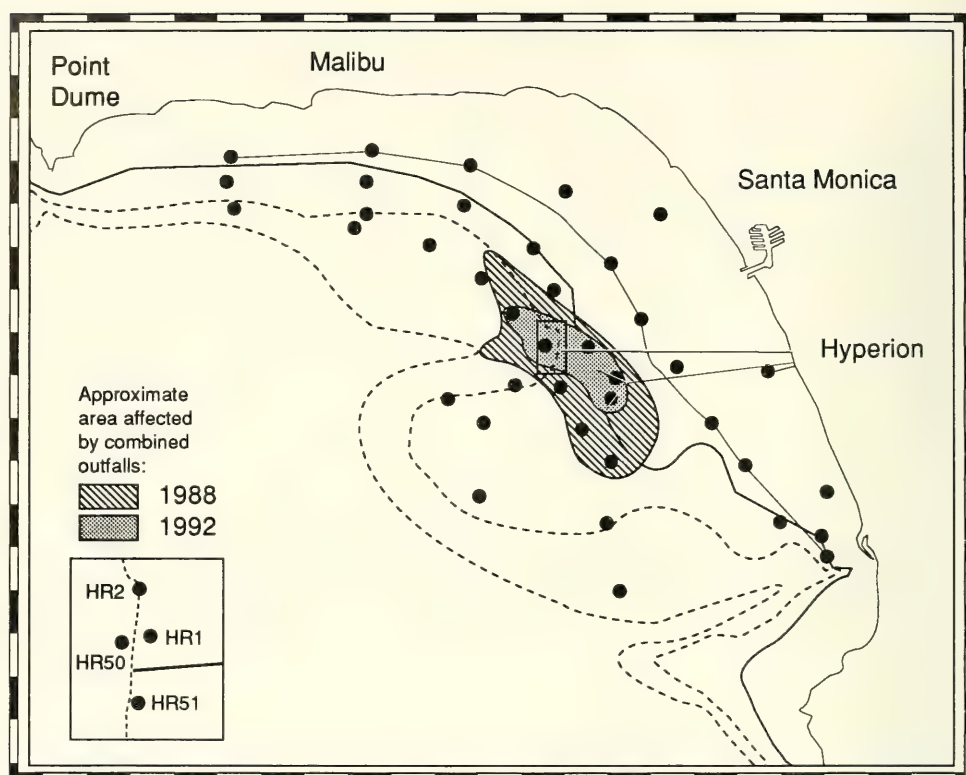


Fig. 9. Approximate extent of infaunal assemblages affected by discharges from the Hyperion outfall system in 1988 and 1992.

In summary, infaunal assemblages have become more natural in composition around Hyperion's functioning 5-Mile outfall, and within the old sludge field of the terminated 7-Mile outfall. This trend is linked to the reduction of mass emissions from the outfalls; sludge disposal from the 7-Mile outfall ceased in 1987, and concentrations of solids in 5-Mile effluent fell from >130 mg/L in 1985 to approximately 30 mg/L at present.

Similar trends have been documented around other major wastewater outfalls in southern California. Anderson *et al.* (1993) noted that the area of altered benthic community around the outfall operated by the Orange County Sanitation District diminished to > 1 km² as mass emissions from the treatment plant diminished in recent years. Mass emissions discharged from the Joint Water Pollution Control Plant's outfall on the Palos Verdes Shelf dropped significantly during the 1970's and 1980's. During this period, the pollution gradient extending northwestward from the outfall shrank so that distant sites that previously were dominated by pollution-resistant species became more similar to cleaner reference sites (Stull *et al.* 1986, Ferraro *et al.* 1991).

The area of sea bottom with infaunal assemblages affected by the combined outfall system has diminished in size from about 51 km² in 1987 (Dorsey 1988) to 16 km² at present (Figure 9). During this period and based on the Pearson-Rosenberg model, assemblages within the old sludge field have shifted along a

pollution gradient from degraded to early transitional, while those around the 5-Mile outfall have changed from polluted to nearly normal. This recovery is expected to continue as long as mass emissions discharged from Hyperion remain at their present low levels.

Acknowledgments

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Survival and Growth of Juvenile *Neanthes arenaceodentata* (Annelida: Polychaeta) in Marine Sediment Taken from the Vicinity of an Ocean Outfall

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Abstract.—Screened sediments taken from the vicinity of the County Sanitation Districts of Orange County, California (Districts) ocean outfall were tested for toxicity to the polychaetous annelid *Neanthes arenaceodentata*. Survival and growth after exposure to sediments were used as the end points. Experiments subjected juvenile worms (2–3 week, post-emergent) taken from a laboratory inbred population, to different test sediments for a 20-day period. Statistical comparisons between results from a test station versus different control sediments and clean seawater control were made. Although there were differences in overall growth between each experiment, individual survival, growth and daily average growth rate, indicated that the sediments from the vicinity outfall were not toxic to *Neanthes arenaceodentata*.

There are many tests to measure the potential toxicological effects of contaminated sediments on marine organisms (Johns, et al. 1991). The simplest test measures survival as the end point after a period of exposure which is generally 96 hours. To obtain a clearer understanding of the potential impact of solid wastes discharged into the marine environment, additional tests have been developed. The most widely used test, at least on the west coast, is the burial-reburial experiment using the benthic amphipod *Rhepoxynius abronius* (Swartz, et al. 1985). A chronic test, which was also developed in the Pacific Northwest, is the juvenile growth test using the polychaetous annelid *N. arenaceodentata* (Johns, et al. 1991). The third type of toxicological test studies the effect of a toxicant over the complete life-cycle (Reish and Gerlinger 1984). Because of the length of time involved, this test has not been widely used.

The polychaetous annelid, *Neanthes arenaceodentata*, was chosen as the test organism because of the availability of a laboratory inbred population which insured a genetically uniform species available throughout the year (Reish, 1957 1976). This species has been utilized as a toxicological test animal in both aquatic and sediment tests. The initial studies which examined effects of contaminated sediments on *N. arenaceodentata* were undertaken by Reish and Gerlinger (1977) and Gerlinger (1979). They tested the effects of mine tailings on survival and reproduction in *N. arenaceodentata* and other polychaete species. These toxic mine tailings prevented reproduction in polychaetes at concentrations less than occurred at the disposal site in Canada. In another study the presence of sediment

reduced the toxicity of copper to *N. arenaceodentata* in an aqueous solution. The copper ions presumably became attached to the sediment particles (Pesch 1979; Pesch and Morgan 1978). Contaminated sediments from Black Rock Harbor, Connecticut did not affect survival, growth, or the number of reproducing pairs of *N. arenaceodentata*. However, the number of eggs per brood was lower but it was not statistically significant from those grown in reference sediment (Pesch, et al. 1991). The authors reported that the number of larvae per brood was statistically significantly lower in the contaminated sediment compared to the reference sediment.

In a series of reports Johns and his associates developed the test procedures for measuring the effects of contaminated sediments on growth of *N. arenaceodentata* (Johns and Ginn 1990a, b; Johns, et al. 1989, 1990, 1991). This test utilized 2–3 week post-emergence juvenile worms which had just begun to feed and subjected them to contaminated and clean sediment. Growth, as measured by an increase in body weight, was determined over a 20-day test period. They found a statistically significant reduction in growth for worms from sediments contaminated with industrial wastes in Puget Sound. Dillon and Moore (1993), Moore and Dillon (1992) and Tay, et al. (1992) have also used this species in similar studies with contaminated sediments. *Neanthes arenaceodentata* has also been used in two interlaboratory experiments; one was an aquatic test (Pesch And Hoffman 1983); the second one dealt with contaminated sediments (Johns and Ginn 1992).

The rationale behind the *N. arenaceodentata* juvenile growth test is that if an animal is able to grow as measured by body weight in a particular environment, then presumably that environment is not toxic to the organism. To validate the juvenile growth test, the body weight of animals exposed to the potentially contaminated sediment is compared to one or more controls, including the initial weight of a group of animals selected at random at the beginning of the test. The body weight of the groups are compared and appropriate statistical analyses are performed to determine whether or not there is a significant difference between those animals exposed to the test sediments and those in the control. If there is no difference between the experiment group and the control, then presumably the test sediment is not toxic to this organism during the period of exposure.

The primary purpose of this study is to determine if the sediments in the vicinity of the Districts' outfall are toxic to marine organisms as measured by the growth of *N. arenaceodentata* under laboratory conditions over a 20-day period as compared to different controls.

Methods

Sediment.—Sediment was collected off Orange County, California, from 30 to 100 m; the majority of the stations were taken from 60 m. Station locations and water depths are given in Table 1 and Fig. 1. Collections were made on April 16–18, July 24, September 8 and October 6, 1992. Stations were selected with increasing distance from the discharge point of the County Sanitation Districts of Orange County's outfall. Additional samples were taken from Newport Canyon in 60 m. Sediment samples were taken with a modified van Veen grab from which about 1.0 liter of material was removed, gently screened, sealed in a plastic container and placed in an ice chest for transporting to the laboratory. Sediment samples were refrigerated at 4° C until used. The sediment samples were analyzed

Table 1. Station locations, sediment collection dates and sediments tested in 1992, Orange County, California.

Station number	Location (latitude and longitude)	Depth (m)
Sea water	—	—
Silica	—	—
Control	33°35'57", 118°05'18"	59
Control A	33°35'44", 118°03'49"	56
Canyon 2	33°36'09", 117°55'56"	55
ZB2	33°34'34", 118°00'31"	56
0	33°34'31", 118°00'31"	56
1	33°34'38", 118°00'53"	56
44	33°34'30", 118°05'22"	242

chemically for trace metals, DDT and PCB 1254 according to the procedures reported in County Sanitation Districts of Orange County, California (1992). Results are reported as mg/kg dry weight for trace metals and ng/g dry weight for DDT and PCB 1254. Seawater and silica were employed as laboratory controls.

Test animals.—Juvenile *Neanthes arenaceodentata* of 2–3 weeks post-emergence age (age from time of fertilization is 5–6 weeks) were taken from laboratory cultures and five animals were placed in each holding container. Five containers were randomly selected and the worms were dried and weighed. This weight was used as the initial body weight for the test. The basic test procedures follow those developed by Swartz, et al. (1985) for the amphipod *Rhepoxynius abronius* as modified for *N. arenaceodentata* by Johns, et al. (1991a).

Initiation of the test.—One liter glass beakers were used as test containers; these were acid washed in 10% nitric acid and rinsed three times with tap water then rinsed three times with deionized water. Five replicates were used with each test sediment. Sediment was placed in each beaker to a depth of 2.0 cm and 750 ml of seawater added. Compressed air was provided to each test container through a pasteur pipette. All four experiments were conducted in a controlled temperature laboratory maintained at approximately 20° C. The five worms within each holding container were randomly transferred to a test container by pouring the contents into the beaker. One ml of a TetraMarin® solution at a ratio of 1.0 g of food to 25 ml of seawater was given to each test container every other day. During the test, each beaker was examined daily to ensure that adequate aeration was provided. On days 3, 6, 9 and 15 one-third of the fluid in each test container was replaced with clean, filtered seawater. The dissolved oxygen, temperature and salinity were measured on days 0, 3, 6, 9, 12, 15 and 20.

Termination of the test.—On day 20 the worms were removed from each test container, counted, placed in a clean, small petri dish and washed in distilled water. All worms from each replicate were placed in a separate pre-weighed aluminum pan and dried at 50° C. The dry weight of the worms in each pan was recorded. The data were recorded as the dry weight per worm per day as calculated using the formula:

$$G = (DW_t - DW_i)/T$$

G = Estimated individual growth rate (mg dry weight per day)

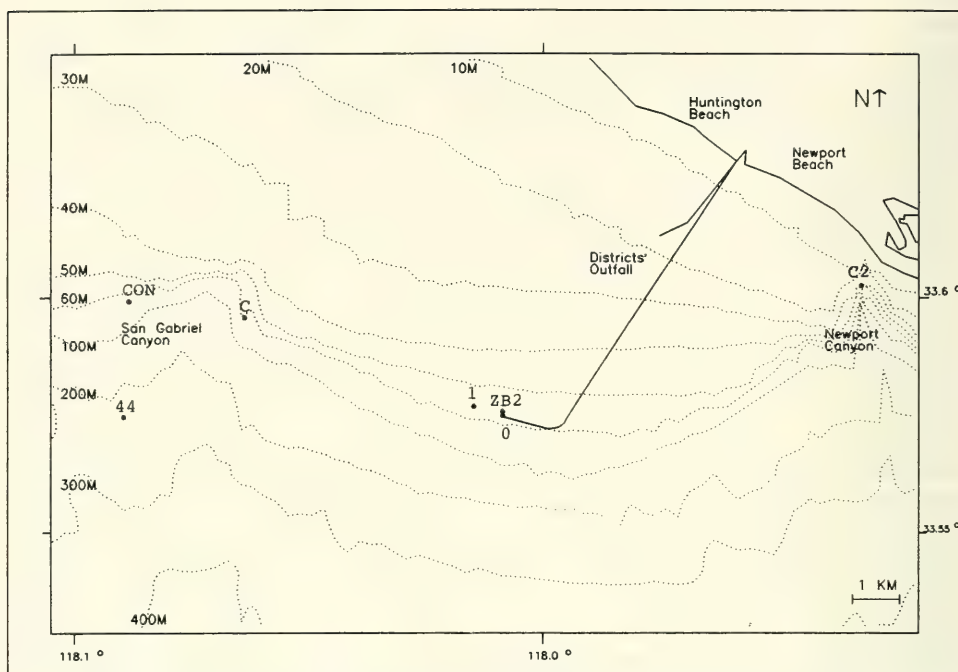


Fig. 1. Station locations, County Sanitation Districts of Orange County, California.

DW_t = Mean estimated individual dry weight (in mg) at the termination of the experiment

DW_i = Mean estimated individual dry weight (in mg) at the initiation of the experiment

T = Exposure time in days

The daily growth rate per worm facilitated comparison of the results between the different test sediments and with other experiments. Since each test is not initiated with exactly the same size (weight) worm, expressing growth as a rate rather than an absolute mass per worm normalized the results to account for these differences. Experimental data were applied to one-way analysis of variance (ANOVA). Tukey's HSD multiple comparisons test was also used. These analyses were performed using the computer statistical software package on SYSTAT (Wilkinson 1990).

Results

Table 2, records the concentration of nine trace metals, total DDT, PCB 1254 and percent total organic carbon. These data were compared to the mean and standard deviations for these chemicals for 1990–1991 sampling period (County Sanitation Districts of Orange County, 1992). The concentration for all chemicals at all stations were within those measured in 1990–1991 except for some trace metals at Station C2 located in Newport Canyon. The concentrations at this station were above the mean and standard deviations for arsenic, copper, chromium, lead, mercury, nickel and zinc. Maurer, *et al.* (in press) indicated that Newport

Table 2. Comparison of sediment and sediment geochemistry from the vicinity of the County Sanitation Districts of Orange County, California, wastewater treatment discharge mean values (April–October 1992).

Station	Median PHI	Organic carbon	Metals ($\mu\text{g/g}$)										Total mean		PCB1254 (ng/g)
			As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	DDT (ng/g)			
CON ²	3.51	0.305	3.16	0.12	17.7	10.5	7.3	0.164	34.64	0.181	34.64	6.07	6.07	4.9	4.9
C ²	3.41	0.331	3.65	0.22	18.7	11.4	8.2	0.244	39.67	0.244	39.67	6.27	6.27	3.6	3.6
1 ¹	3.61	0.393	3.55	0.43	19.1	15.8	8.9	0.492	41.43	0.492	41.43	5.61	5.61	4.7	4.7
0	3.48	0.504	3.49	1.07	20.4	21.8	10.4	0.720	49.63	0.720	49.63	4.90	4.90	4.1	4.1
ZB2	3.54	1.384	3.43	0.69	18.5	16.7	8.0	0.526	42.41	0.526	42.41	4.62	4.62	3.5	3.5
C2	6.67	1.479	11.00	0.68	34.4	31.9	26.8	0.226	103.42	0.226	103.42	23.00	23.00	5.9	5.9
44 ²	6.52	2.208	8.50	1.11	57.0	51.9	24.5	0.328	87.60	0.328	87.60	47.90	47.90	5.1	5.1

¹ Dry weight.² Data only for July.

Table 3. Percent survival of *Neanthes arnaccodentata* exposed to sediment off Orange County, California (25 test animals per experiment except as noted).

Station	Dates of sediment collection (1992)			
	April	July	September	October
Sea water control	96%	84%	96%	96%
Silica control	100	88	100	100
CON	87 ¹	89 ¹	—	100
C	—	76	—	88
0	95	92	92	92
1	—	99	—	100
ZB2	92	96	—	88
C2	—	92	—	100
44	—	100	—	—

¹ 75 test animals.

Canyon acts as sediment trap for metals. Individual worm growth per day was less at this station, but not statistically significant, than some of the stations located near the outfall, but was greater than those measured in the seawater and three of the four silica controls. Based on these data the chemical composition of the sediments apparently does not have an affect on the survival and growth of this worm.

Water quality monitoring data.—The water quality monitoring data for temperature, salinity and dissolved oxygen were generally uniform between replicates of a test sample, between test samples within an experiment, and between experiments. Water temperature for all experiments ranged from 19.8 to 21.8°C with a mean and standard deviation of $20.8 \pm 0.6^\circ \text{C}$. Salinity ranged from 30.1 to 33.8 ppt with a mean and standard deviation of 33.0 ± 0.7 ppt for all experiments. The dissolved oxygen concentration ranged from 5.3 to 6.8 mg/L with a mean and standard deviation of 6.3 ± 0.3 ml/L for all experiments. These data indicated that the water quality conditions were good for this species throughout the 20-day experimental period.

Biological data.—The percent survival was above 90% in 18 of the 25 test samples and above 80% in all but one test concentration (Table 3). The survival rate of the worms was over 90%, with one exception, for those animals exposed to sediment collected from the stations nearest the outfall (Stations 0, 1, and ZB2). There was no statistical difference in survival between the five replicates within a test sample, the different samples within a test, or between the four experiments (Table 4; Figs. 2–5).

The mean growth rate per worm per day ranged from a low of $0.23 \mu\text{g}$ dry weight in the sea water control for April 1992 to a high of 0.98 at Station 0 for September 1992 (Figs. 2 to 5). In general, the lowest growth rates were those worms in the sea water and silica controls. However, in the July 1992 experiment the daily growth rate of those worms exposed to silica was $0.79 \mu\text{g}$ dry weight which was exceeded only by the $0.85 \mu\text{g}$ measured for Station 0 for this experiment (Fig. 3). In the other three experiments the growth rate was slightly greater in the silica controls than the sea water control (Figs. 2, 4–5). The daily growth rate of the worms was generally higher in the sediment collected near the outfall (Stations 0 and ZB2; Figs. 2–5). The growth rate of worms in the sea water control was

Table 4. Growth per day per worm exposed to sediment off Orange County, California (growth in μg dry weight).

Station	April growth per worm		July growth per worm		September growth per worm		October growth per worm	
	Mean	$\pm$ S.D.	Mean	$\pm$ S.D.	Mean	$\pm$ S.D.	Mean	$\pm$ S.D.
Sea water (control)	0.25	0.02	0.43	0.20	0.60	0.06	0.32	0.11
Silica (control)	0.23	0.03	0.79	0.28	0.62	0.19	0.41	0.09
Con (control)	0.31	0.11	0.62	0.14	—	—	0.37	0.07
C (control)	—	—	0.68	0.33	—	—	0.34	0.12
1 (ZID boundry)	—	—	0.52	0.2	—	—	0.35	0.08
0 (ZID)	0.33	0.07	0.85	0.29	0.98	0.23	0.49	0.07
ZB2 (ZID)	0.35	0.07	0.64	0.23	—	—	—	—
C2 (canyon)	0.29	0.06	0.55	0.2	—	—	0.43	0.07
44 (deep dump site)	—	—	0.67	0.05	—	—	—	—

significantly less than those worms exposed to sediment from Station ZB2 in April (Fig. 2) and October (Fig. 5) Station 1 in the September experiment (Fig. 4) and Station 0 in July, September and October (Figs. 3–5). Growth of worms exposed to the silica control in the April experiment (Fig. 2) was less than those placed in sediment from Stations 0 and ZB2. Although this response was not statistically significant. All replicates in all experiments were fed the same amount of food. The only source of food in the sea water and silica controls was the TetraMarin®. Those animals exposed to the offshore sediments had an organic source of nutrients in addition to the TetraMarin®.

Discussion

The high percentage of survival of the worms in all four tests taken between April and October 1992 (Table 3) contrasts with that reported by Johns and Ginn (1990a) for sediments collected from Puget Sound, Washington. In their experiments using the same test procedures and test animals from the same inbred laboratory colony of *Neanthes arenaceodentata*, they found a high percentage of survival of this species in all sediments except those from the inner reaches of Elliot Bay region of Puget Sound where less than 10% survived. Industrial wastes have been discharged into Elliot Bay over a long period of time. This contrasts with domestic wastes discharged by the Districts off Orange County, California. Concentrations of many of the trace metals and organics were high in the sediments from the inner reaches of Elliot Bay. For example, copper concentration measured 720 mg/kg dry weight, zinc 2,400, and PCBs 1,7000 $\mu\text{g}/\text{kg}$ dry weight (Johns, et al. 1991). These amounts are much higher compared to mean values reported by the Orange County Sanitation Districts (1992) for copper (20 mg/kg dry weight), zinc (46 mg/kg dry weight), and PCBs (highest value 0.00015 $\mu\text{g}/\text{kg}$ dry weight). The amounts of these contaminants from inner Elliot Bay, were over one order of magnitude higher for copper and zinc and several orders of magnitude higher for PCBs. Based on these comparative figures, the concentrations of trace metals and organics present in the vicinity of the Districts' outfall are sufficiently low as to not cause any toxicological effect to these polychaetes over a 20-day experimental period.

Experimental variability in the mean growth rate per worm per day was noted

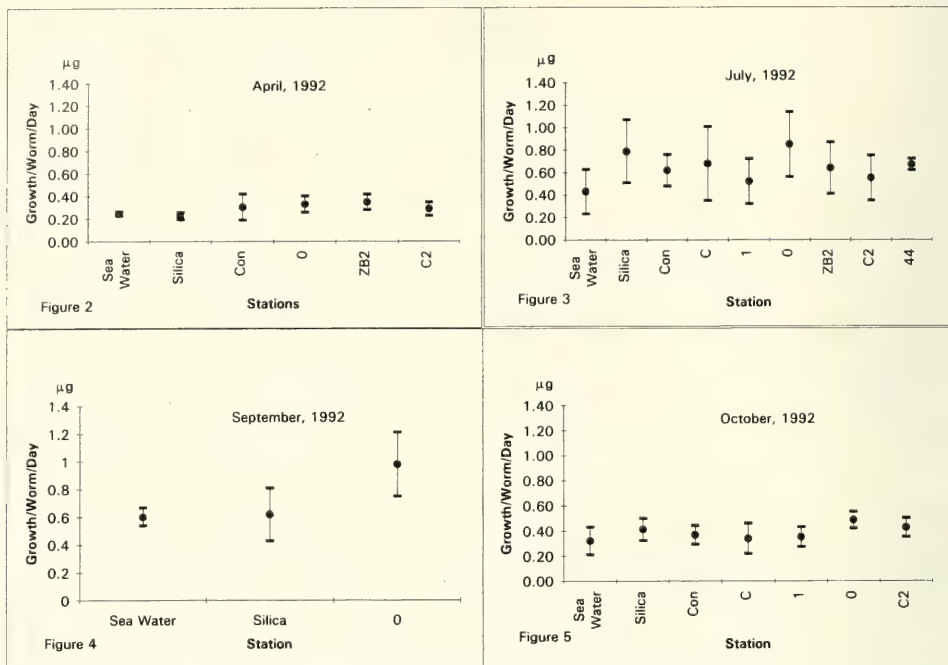


Fig. 2. Mean growth and standard deviations per worm per day for the April 1992 experiment. Data in μg dry weight.

Fig. 3. Mean growth and standard deviations per worm per day for the July 1992 experiment. Data in μg dry weight.

Fig. 4. Mean growth and standard deviations per worm per day for the September 1992 experiment. Data in μg dry weight.

Fig. 5. Mean growth and standard deviations per worm per day for the October 1992 experiment. Data in μg dry weight.

in two ways: (1) according to the experiment (Fig. 2 to 5), and (2) according to the station location (Fig. 2 to 5). The daily growth rate was highest in the sediment collected in September and lowest in the April collections.

There was no significant difference in growth rate between field collected sediments in any one experiment but there was statistically significant difference between every experiment when all stations were pooled.

Since all worms were of similar size and from the same laboratory colony maintained since 1964 (Reish 1976), it is difficult to account for these differences. There does not appear to be a seasonal difference in the chemistry of the waste water discharge or sediment (Orange County Sanitation Districts, 1992). Furthermore, no explanation can be given as to why the growth rate in the silica control was so high in the July experiment and low in the other three. All sediment samples were taken from the 60 m isobath except Station 44 at a depth of 242 m for the July collection. The daily growth rate at this station was similar to those other sediment samples collected on this date (Fig. 3).

Conclusions

The effect of offshore sediment on survival and growth rate was measured over a 20-day period on the young of the polychaetous annelid *Neanthes arenaceo-*

dentata. Sediments were collected from near the Districts' waste water discharge. Survival was greater than 90% in nearly all samples for all experiments. These data indicate that the sediment from the vicinity of the outfall is not toxic to this species of polychaete. The variability in the results from sediment to sediment, and experiment to experiment indicates that growth rate is highly variable in this species, and it may not be a suitable test end point for use in assessing the environmental condition of the sediments in the vicinity of a domestic discharge. Apparently industrial wastes can be toxic, as indicated by the studies in Puget Sound (Johns and Ginn 1990b), but primary-secondary treated domestic wastes are not toxic to this species. It would be important to determine whether these sediments affect reproduction and survival of the offspring in this or other infaunal species of marine animals. The findings reported by Pesch, *et al.* (1991) indicated that while toxicity of contaminated sediments may not affect the parent generation, it may affect the next generation. Studies are underway to determine if there is any effect of these on reproduction, the number of juveniles produced and whether or not a relationship exists between these biological measurements and the concentration of contaminants in the body of the worm.

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An Overview of Hepatic Neoplasms, Putatively Preneoplastic Lesions, and Associated Conditions in Fish Sampled during the County Sanitation Districts of Orange County's 1986-1992 Ocean Monitoring Program

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Abstract.—As part of the County Sanitation Districts of Orange County's ocean monitoring program, livers of 705 bigmouth sole *Hippoglossina stomata* Eigenmann & Eigenmann, 714 hornyhead turbot *Pleuronichthys verticalis* Jordan & Gilbert, and 806 white croaker *Genyonemus lineatus* (Ayres) were collected by otter trawl and rig fishing at eight sampling stations between 1986-1992.

Histopathological appraisal of these livers revealed highest prevalences of neoplasms at the outfall (2.8%), within the ZID or zone of initial dilution, 60 m on either side of the diffuser (2.4%), and at an 18m inshore station, near the mouth of the Santa Ana River (1.8%). Age as a risk factor was significant: 100% of bigmouth sole, 66.6% of hornyhead turbot, and 88.9% of white croaker with liver neoplasms exceeded mean standard lengths.

The County Sanitation Districts of Orange County included fish liver histopathology in their ocean monitoring program's protocol in order to evaluate possible relationships between toxicopathic alterations and exposures to chemical contaminants such as PCBs and chlorinated pesticides.

Their goals were to identify hepatic lesions in demersal and ubiquitous "target" species, to ascertain if such lesions were more prevalent at more contaminated sites, and if so, to correlate the occurrence of these "biomarkers" with sediment and tissue chemistry profiles unique to respective sampling stations.

What follows is a brief overview of this study, conducted between 1986-1992. Details regarding three types of lesions are presented: neoplasms, putatively preneoplastic foci of cellular alteration and severe hydropic vacuolation. A more comprehensive account of these and other lesion categories, together with results and interpretation of chemical analyses, will appear elsewhere (Year 10 Annual Report of the County Sanitation Districts of Orange County).

Methods

Liver dissections were performed on board, on fresh-killed fish only. Sexes, standard lengths (mm) and weights (gm) of bigmouth sole, hornyhead turbot and white croaker were recorded from eight collecting stations.

Unless occasional external hepatic lesions were also evident, all 2-3 mm-thick samples were excised from the central portion of the liver. These were fixed immediately in 10% neutral buffered formalin, after which they were transported to the Department of Pathology at the University of Southern California School

Table 1. Types of hepatic lesions recorded among 2,225 bigmouth sole, hornyhead turbot and white croaker from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1986-1992).

LESION CATEGORIES

Neoplasms

Cholangiocellular carcinoma

Cholangioma

Liver cell adenoma,

Basophilic variant

Clear cell variant

Eosinophilic variant

Foci of Cellular Alteration

Basophilic foci

Clear cell foci

Eosinophilic foci

Severe Hydropic Vacuolation ("RAM cells")

of Medicine where they were dehydrated in an alcohol series, cleared in "Clear-Rite 3", and embedded in paraffin (Tissue Prep 2). Sections were cut at 4 micra, placed on "poly-L-lysine-coated" slides, stained with Gill's and Weigert's hematoxylin and counterstained with eosin.

No significant microscopic lesion was documented unless its diagnosis was also independently confirmed by Mark S. Myers, Chief of Pathology, National Marine Fisheries Service, Seattle, Washington.

Lesions categories are presented in Table 1. Representative slides of each of these will be archived in the National Registry of Tumors at the Smithsonian Institution, Washington, D.C. (Harshbarger and Clark, 1990).

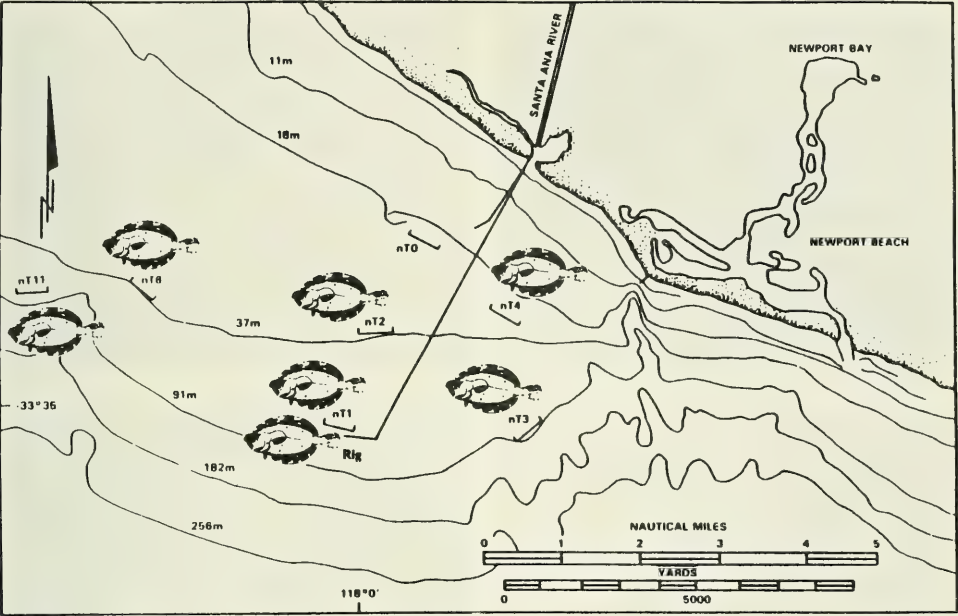


Fig. 1. Location of otter trawl and rig sampling stations (bigmouth sole). County Sanitation Districts of Orange County, California.

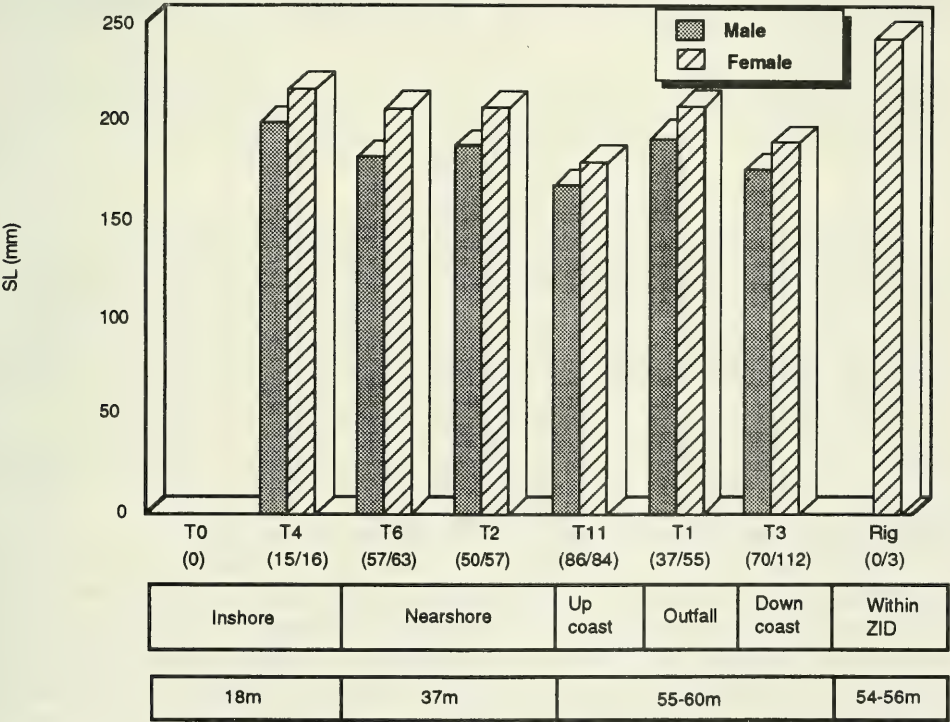
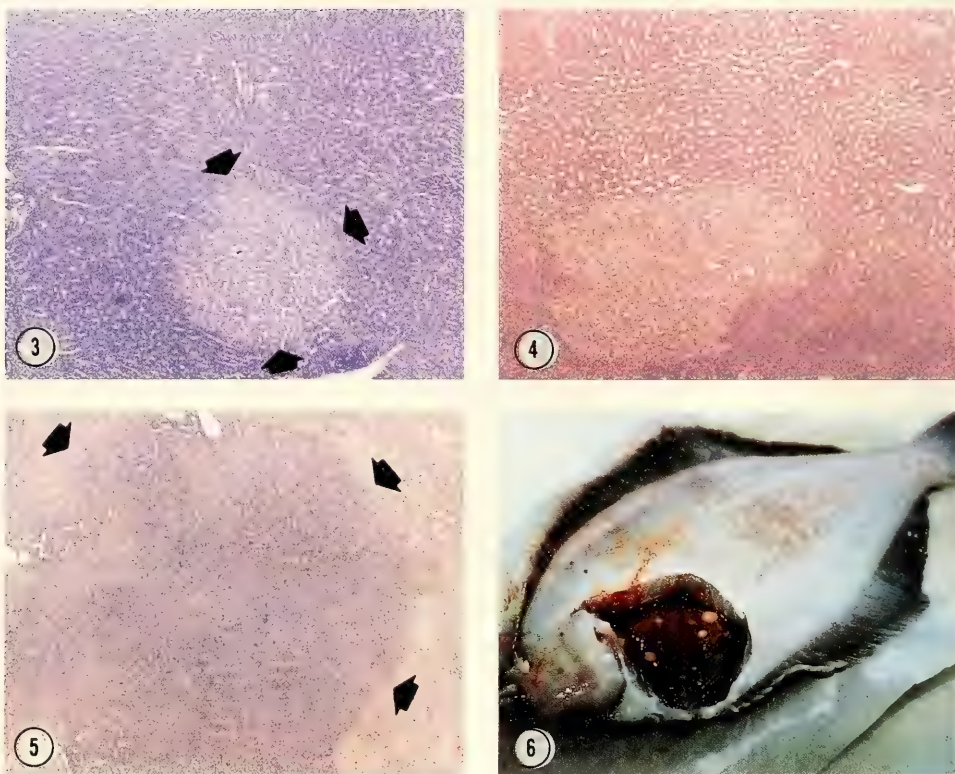


Fig. 2. Average standard lengths of 705 bigmouth sole (315M:390F) from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1988-1992).



Figs. 3–6. Representative micrographs of H&E-prepared liver lesions: (3) eosinophilic FCA in bigmouth sole (arrows delineate the idiopathy) $\times 40$; (4) clear cell FCA in hornyhead turbot $\times 40$; (5) basophilic variant liver cell adenoma in hornyhead turbot $\times 40$; (6) gross appearance of multiple, clear cell variant liver cell adenoma nodules in hornyhead turbot (see Fig. 7).

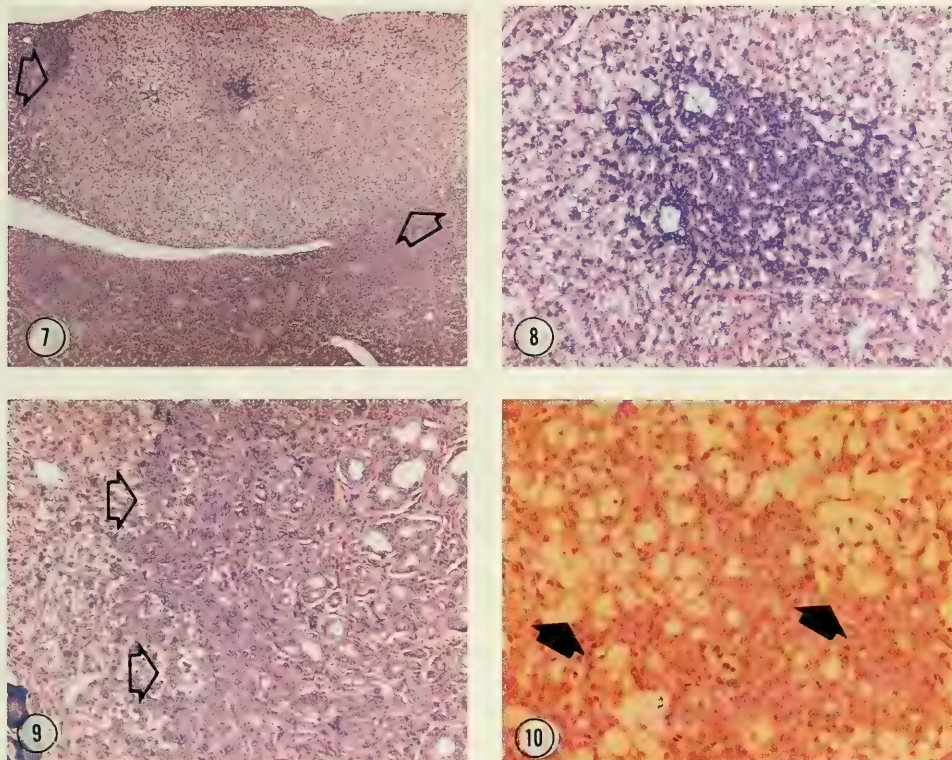
Results

Bigmouth sole *Hippoglossina stomata*.—The local distribution pattern of this species includes seven of eight sampling stations: T4 (18m inshore), T6 and T2 (37m nearshore), T11 and T3 (55–60m upcoast and downcoast reference sites), T1 (the 55–60m outfall) and RIG (54–56m, within the ZID). Bigmouth sole were absent only from T0, an 18m inshore station near the mouth of the Santa Ana River (Fig. 1).

Since otoliths were not analyzed, standard lengths were used to estimate age. Figure 2 indicates that specimens from station T11 tend to be smaller; hence, they are presumably younger. This is supported by the fact that 14% of the 170 bigmouth sole sampled at station T11 were sexual indeterminants.

The following types of liver lesions were documented among 705 bigmouth sole: two with basophilic foci of cellular alteration (FCA), seven with eosinophilic FCA (Fig. 3), one with clear cell variant liver cell adenoma, three with basophilic variant liver cell adenoma, and two with eosinophilic variant liver cell adenoma.

Figure 11 illustrates that the combined prevalence of neoplasms (NEOs) and foci of cellular alteration (FCA) is highest at station T1, the outfall. Elevated numbers of NEOs at station T4 may be a distortion, given that only 31 specimens were sampled.



Figs. 7–9. Representative micrographs of H&E-prepared liver lesions: (7) clear cell variant liver cell adenoma in hornyhead turbot (arrows delineate the idiopathy) $\times 25$; (8) basophilic FCA in white croaker $\times 100$; (9) invasive cholangiocellular carcinoma (to right of arrows) in white croaker $\times 100$.

Fig. 10. Severe hydropic vacuolation in hepatopancreatic parenchyma of white croaker (clusters of impacted cells are indicated by arrows), Oil Red O, $\times 200$.

Hornyhead turbot *Pleuronichthys verticalis*.—This species occurs at all stations except the ZID, which is designated RIG (Fig. 12). Mean standard lengths are comparable at all stations (Fig. 13).

The following types of liver lesions were observed among 714 hornyhead turbot: two with basophilic FCA, two with clear cell FCA (Fig. 4), 19 with eosinophilic FCA, one with cholangiocellular carcinoma, one with basophilic variant liver cell adenoma (Fig. 5), one with clear cell variant liver cell adenoma (Figs. 6–7), and one with eosinophilic variant liver cell adenoma.

Figure 14 depicts a 5.0% prevalence of NEOs at outfall station T1. Also of interest is the prevalence of eosinophilic FCA in specimens from stations T6 (8.5%) and T1 (6.7%).

White croaker *Genyonemus lineatus*.—White croaker occur at all stations except T6 and T11 (Fig. 15). Throughout the range of this species, standard lengths tend to be larger at the RIG site or zone of initial dilution (Fig. 16).

The following types of liver lesions were recorded among 806 white croaker: 11 with basophilic FCA (Fig. 8), five with cholangioma, eight with cholangiocellular carcinoma (Fig. 9), and 168 with various degrees of severe hydropic vacuolation (Fig. 10).

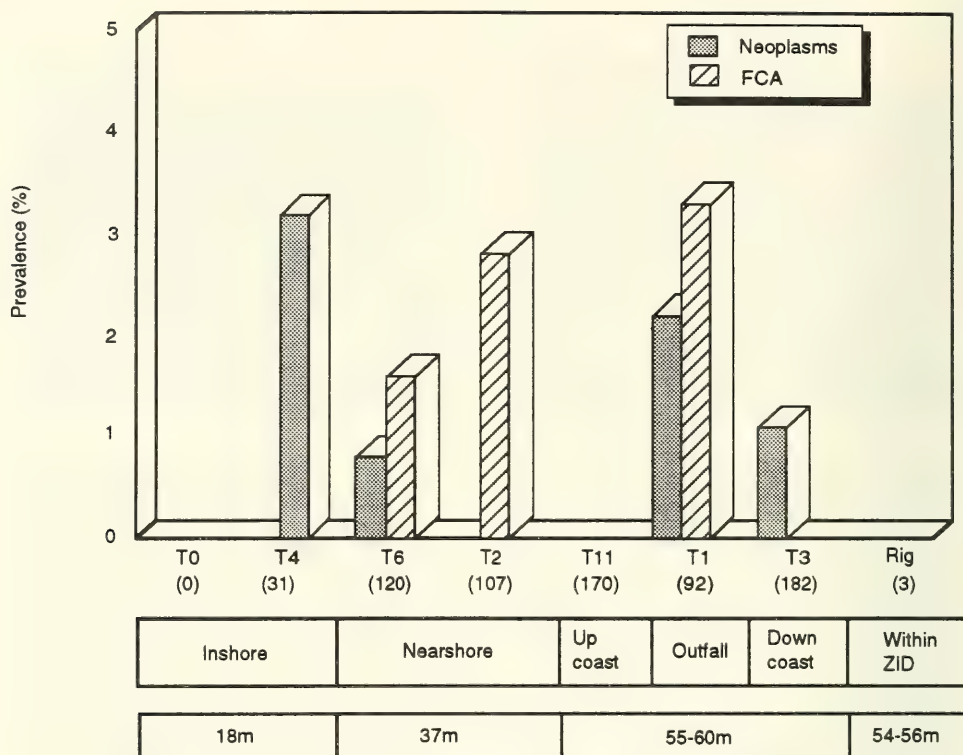


Fig. 11. Prevalences of hepatic lesions in 705 bigmouth sole from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1988-1992).

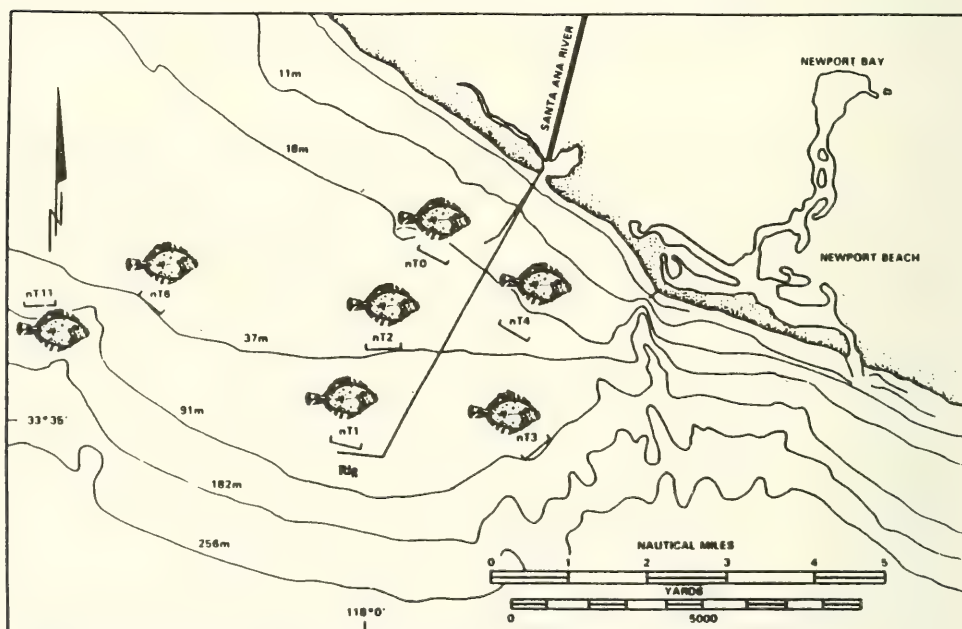


Fig. 12. Location of otter trawl and rig sampling stations (hornyhead turbot). County Sanitation Districts of Orange County, California.

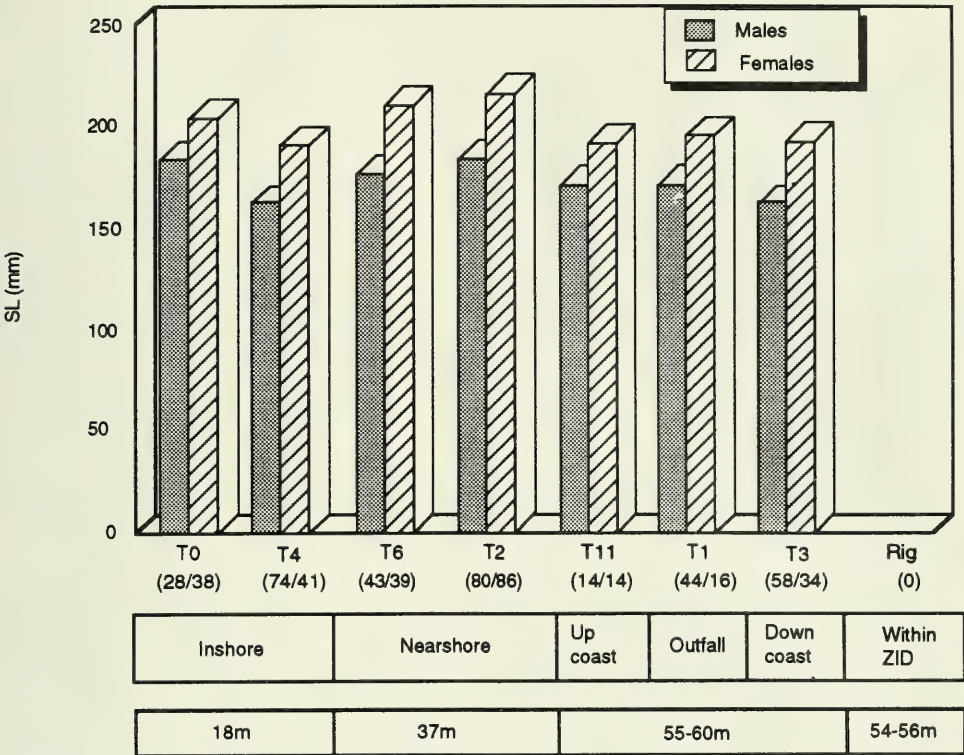


Fig. 13. Average standard lengths of 609 hornyhead turbot (341M:268F) from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1988–1992).

Figure 17 indicates that neoplasm prevalence at stations where $n > 60$ ranks highest at the RIG site (2.4%) and at T0 (2.2%). White croaker from these same stations also rank highest relative to prevalence of severe hydropic vacuolation: 39.4% at the RIG site and 18.0% at T0 (Fig. 18).

Discussion

Results of this study suggest that correlations exist between the age of fish—as determined by extrapolation of standard lengths—and the presence of neoplasms, foci of cellular alteration and severe hydropic vacuolation.

For example, when the standard length of an impacted fish is compared to all nonimpacted fish at the same station, of the same species, the results (based on 1988–1992 data) are as follows: 88.9% of all white croaker with liver neoplasms (NEOs), 83.3% with foci of cellular alteration (FCA) and 85.1% with severe hydropic vacuolation exceeded mean standard lengths (Tables 2–3). Similarly, 100% of all bigmouth sole with NEOs and 70.0% with FCA exceeded mean standard lengths (Table 4). Among hornyhead turbot, 66.6% with NEOs exceeded mean standard lengths (Table 5). Hence, one may conclude that direct correlations do indeed exist between age/standard length of a fish and the likelihood of it manifesting one or more of the preceding types of lesion (Love *et al.*, 1984; Myers *et al.*, 1987).

There are also indications that sex is possibly a risk factor in terms of lesion

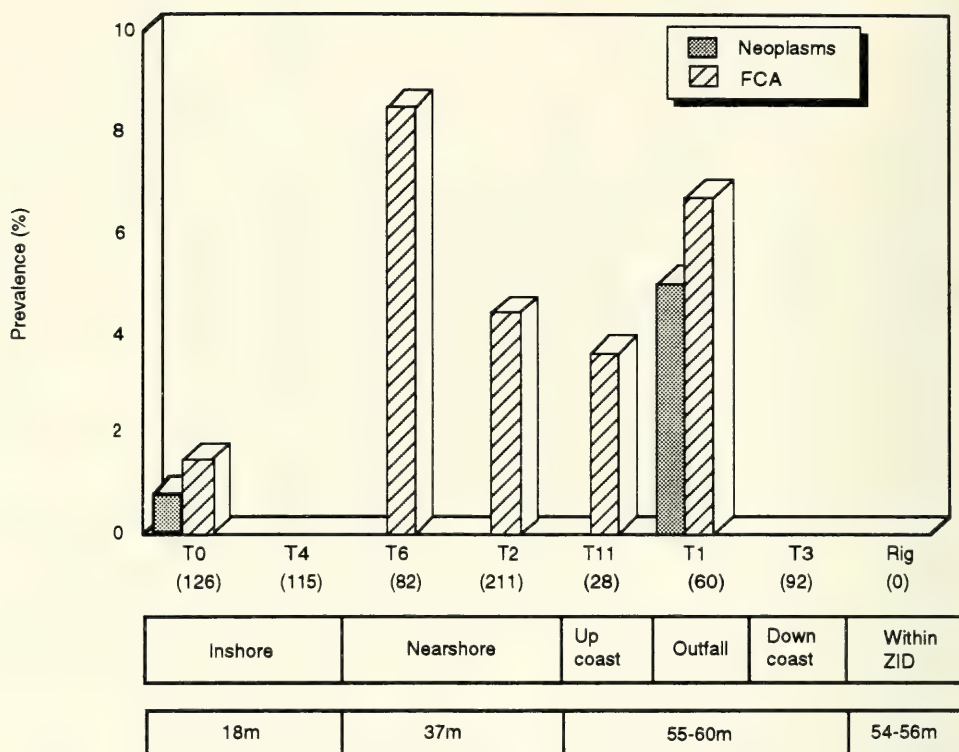


Fig. 14. Prevalences of hepatic lesions in 714 hornyhead turbot from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1986-1992).

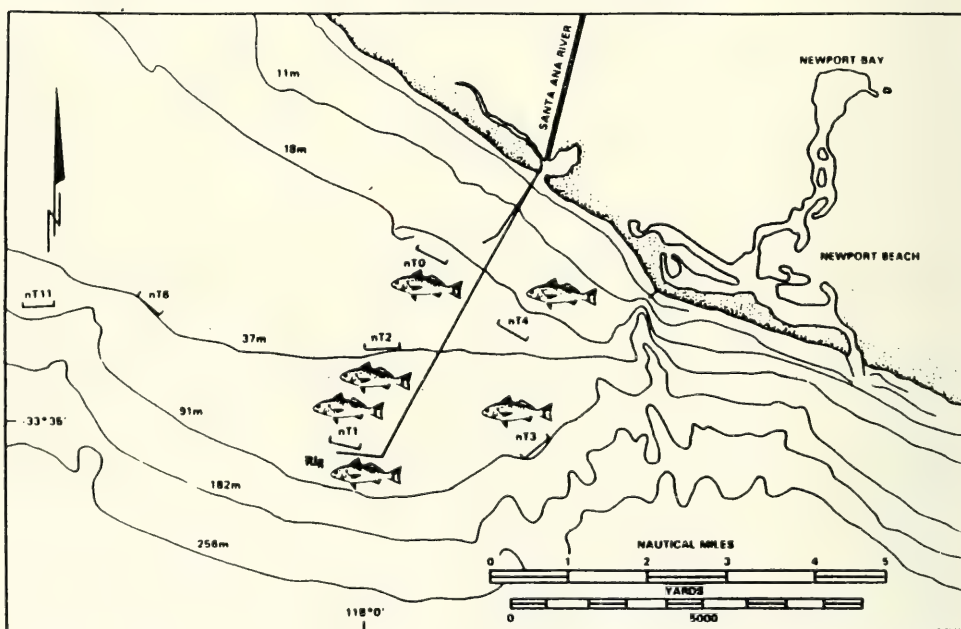


Fig. 15. Location of otter trawl and rig sampling stations (white croaker). County Sanitation Districts of Orange County, California.

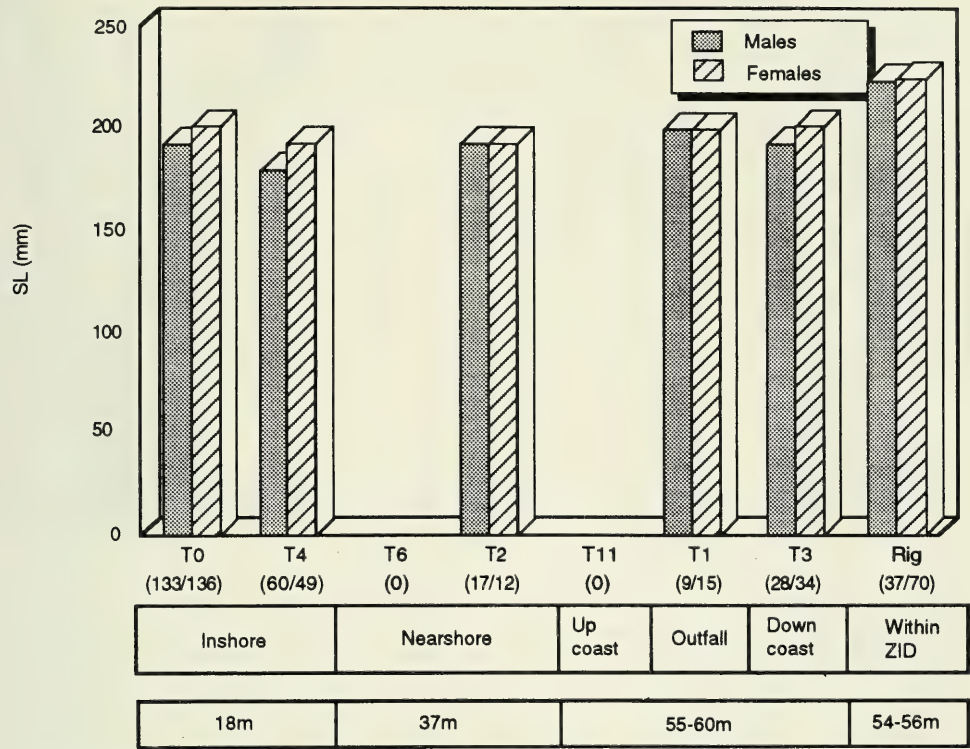


Fig. 16. Average standard lengths of 600 white croaker (284M:316F) from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1988–1992).

prevalence. For example, 76.2% of all hornyhead turbot with eosinophilic foci of cellular alteration were male. On the other hand, 68.4% of all white croaker with severe hydropic vacuolation were female.

The prevalence of severe hydropic vacuolation in liver cells of white croaker from the RIG site (39.4%) and station T0 (18.0%) is also of interest (Fig. 18). This condition was at one time referred to as “RAM” cells—a term no longer valid because it is non-descriptive. Currently such cells are considered by most authorities to be legitimate biomarkers of environmental contamination (Moore *et al.* 1989; Hinton 1990; Hinton *et al.* 1992; Bodammer and Murchelano 1990; Stehr 1990; Stehr *et al.* 1991; Murchelano and Wolke 1985, 1991). In other fish species, severe hydropic vacuolation occurs as much as 48% in winter flounder from Boston Harbor and 50% in starry flounder from San Francisco Bay's Hunters Point (Johnson *et al.* 1992; Myers *et al.* 1993). Recent research conducted by the National Benthic Surveillance Project confirms that severe hydropic vacuolation in white croaker varies according to site: e.g., Castro Creek (40%), Long Beach (35%), Cerritos Channel (25%), San Pedro (20%), and Dana Point (10%). According to their findings, risk factors for this condition are sediment and liver tDDT, liver tPCB, liver chlordane and liver dieldrin (Myers *et al.* 1994).

Figure 19 illustrates the overall prevalences of neoplasms and foci of cellular alteration (FCA) at eight sites where the three target species have been sampled since 1986. Because eosinophilic FCA among hornyhead turbot have not yet been

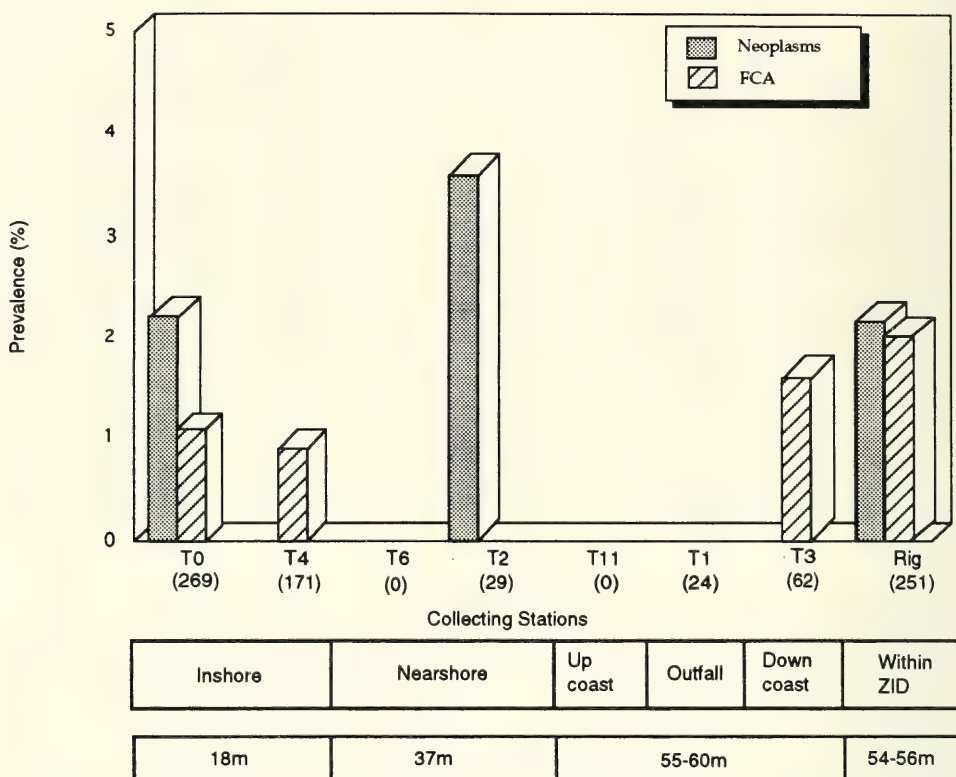


Fig. 17. Prevalences of hepatic lesions in 806 white croaker from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1986–1992).

proven to be valid preneoplastic lesions, their elevated numbers at stations T6, T2 and T1 are of unknown significance. Notwithstanding, the National Benthic Surveillance Project has reported that possibly significant risk factors for this condition in hornyhead turbot from West Santa Monica Bay, California stem from nonDDT pesticides and dieldrin in sediments (Myers *et al.* 1993). By contrast, FCA at the RIG site are more likely significant because all are of the preneoplastic basophilic variety (Susani *et al.* 1986).

In summary, liver neoplasms are an important indicator of contaminant exposure (Johnson *et al.* 1992; Landahl *et al.* 1990; Malins *et al.* 1987; Myers *et al.* 1991, 1993). Examples of liver neoplasm prevalences previously reported in the literature (Johnson *et al.* 1992; Myers *et al.* 1993) include English sole from Seattle's Duwamish River (16%), black croaker from North San Diego Bay (13%), winter flounder from Boston Harbor (9%), white croaker from Cerritos Channel in San Pedro Bay (5%), and hornyhead turbot from West Santa Monica Bay (3%). As illustrated in Figure 19, Orange County's outfall at T1 is most impacted (2.8% neoplasms), followed by the ZID at the RIG site (2.4% neoplasms), and 18 m inshore station T0 near the mouth of the Santa Ana River (1.8% neoplasms).

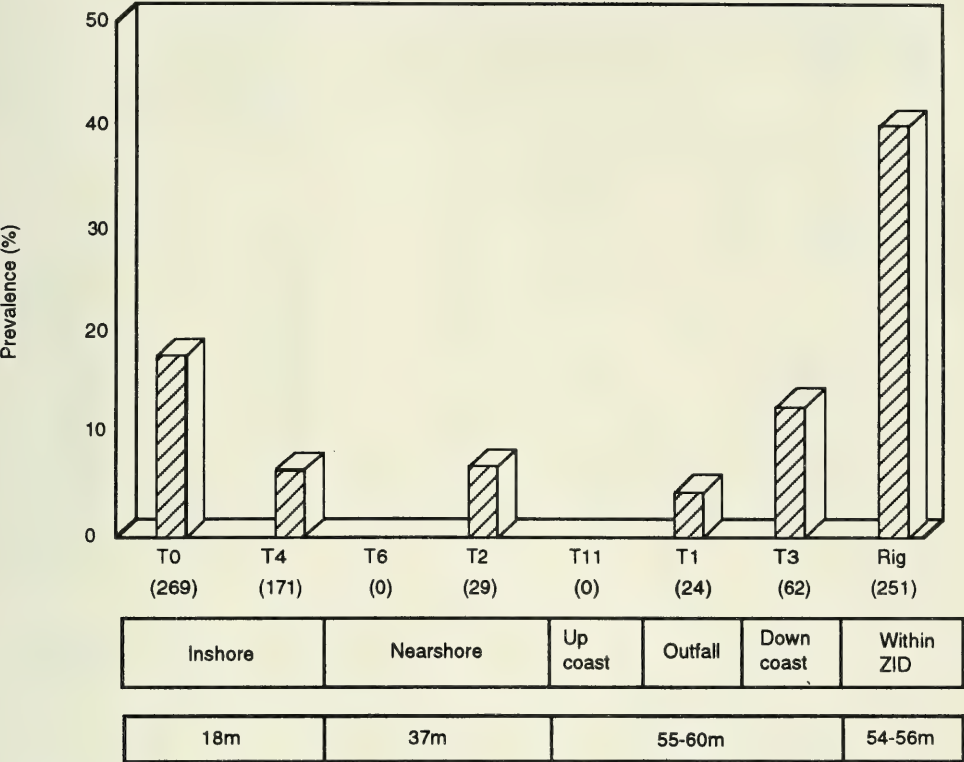


Fig. 18. Prevalence of severe hydropic vacuolation in hepatopancreatic parenchyma of 806 white croaker from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1986-1992).

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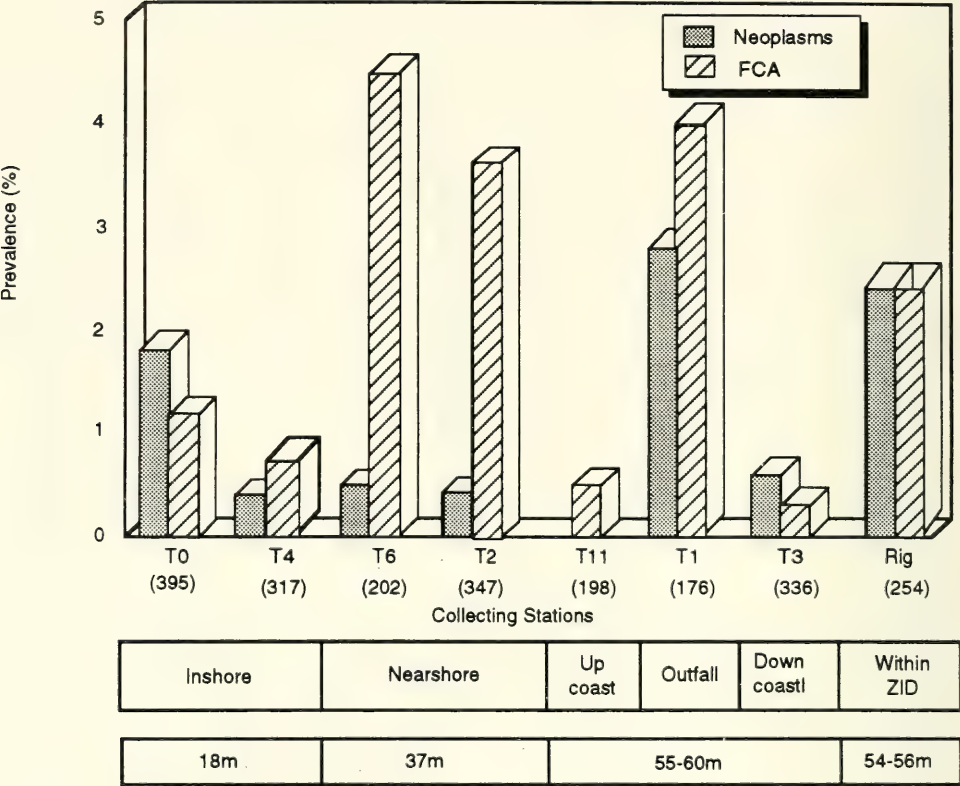


Fig. 19. Overall prevalences of hepatic neoplasms and foci of cellular alteration in 2,225 bigmouth sole, hornyhead turbot and white croaker from sampling stations of the County Sanitation Districts of Orange County's ocean monitoring program (1986-1992).

Table 2. Age as a risk factor for hepatic neoplasms (NEO) and preneoplastic foci of cellular alteration (FCA) among 15 of 600 white croaker sampled during the County Sanitation Districts of Orange County's 1988-1992 ocean monitoring program. Note that 8/9 (88.9%) of fish with NEO and 5/6 (83.3%) with FCA exceeded the mean standard length.

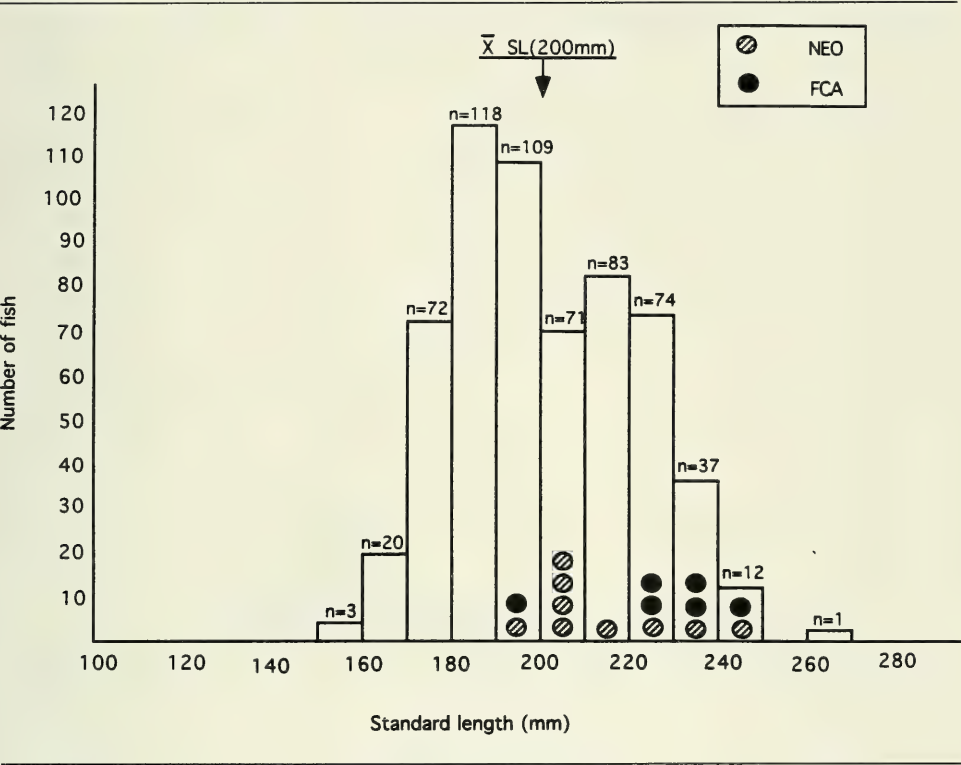


Table 3. Age as a risk factor for severe hydropic vacuolation (SHV) of hepatopancreatic parenchyma among 114 of 600 white croaker sampled during the County Sanitation Districts of Orange County's 1988-1992 ocean monitoring program. Note that 97/114 (85.1%) of impacted fish exceeded the mean standard length.

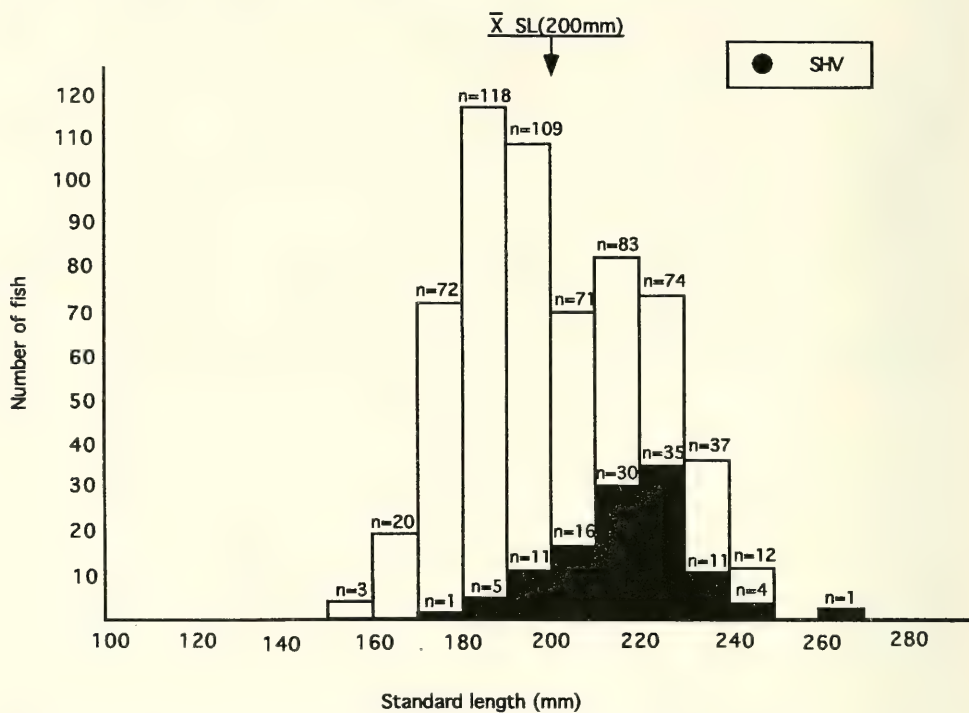


Table 4. Age as a risk factor for hepatic neoplasms (NEO) and preneoplastic foci of cellular alteration (FCA) among 16 of 705 bigmouth sole sampled during the County Sanitation Districts of Orange County's 1988-1992 ocean monitoring program. Note that 6/6 (100.0%) of fish with NEO and 7/10 (70.0%) with FCA exceeded the mean standard length.

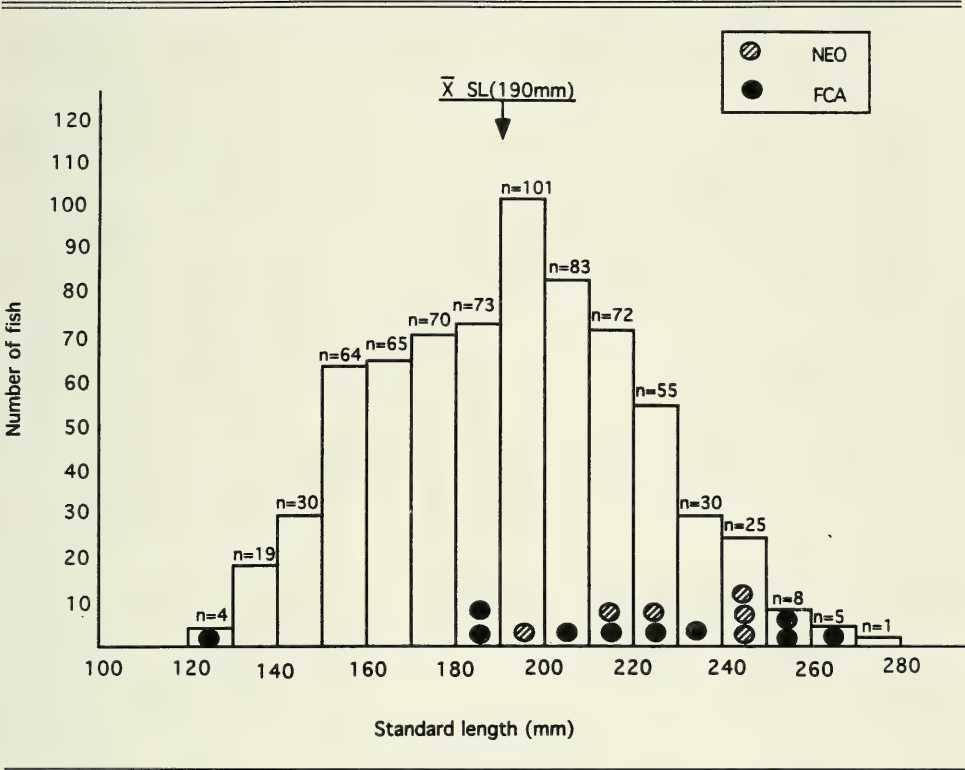
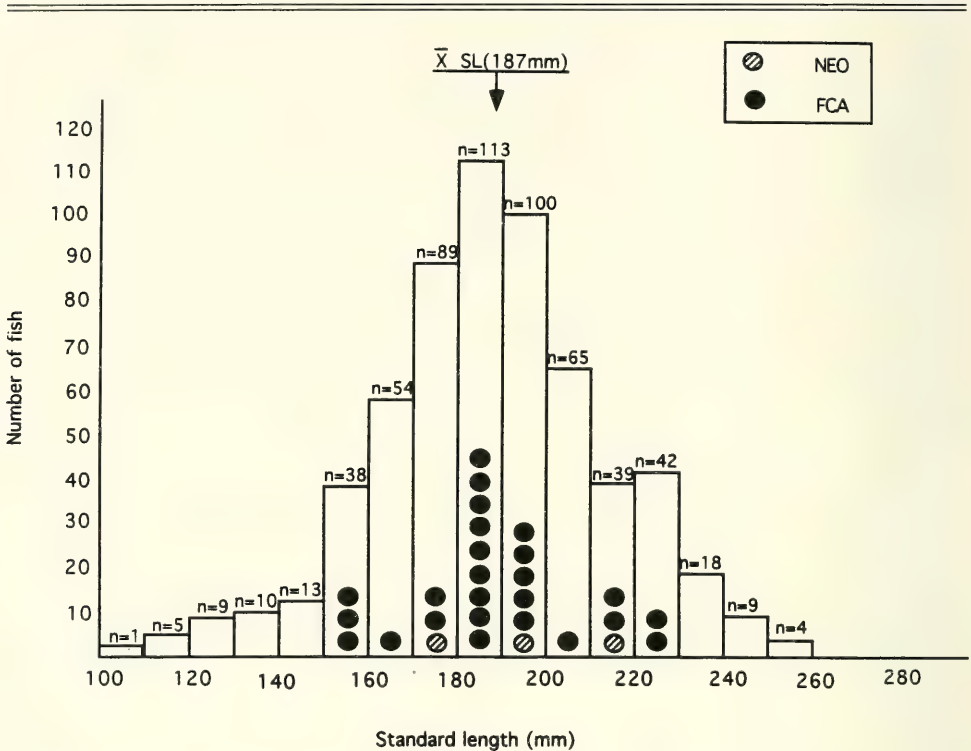


Table 5. Age as a risk factor for hepatic neoplasms (NEO) and preneoplastic foci of cellular alteration (FCA) among 28 of 609 hornyhead turbot sampled during the County Sanitation Districts of Orange County's 1988–1992 ocean monitoring program. Note that 2/3 (66.6%) of fish with NEO but only 10/25 (40.0%) with FCA exceeded the mean standard length.



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Wastewater Bacteria and Shellfish

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Abstract.—Extensive field and laboratory studies were conducted from 1986 to 1989 to determine relationships between wastewater discharges and bacteria in shellfish. Dyed wastewater plume studies showed rapid decrease in recoverable bacteria in seawater. Weekly measurement of water column bacteria throughout the study area over a year-long period showed that waters met the standards for approved growing waters for shellfish. Nevertheless, some shellfish tissue samples exceeded market standards for total and fecal coliform bacteria. Thus, spatial deployments of oysters and mussels were used to evaluate potential sources of bacteria. Bacterial concentrations in shellfish showed poor correlation with periods of disinfection and non-disinfection of wastewater discharges. Bacteria in shellfish correlated with periods of stormwater runoff. Laboratory studies determined the rate of uptake and depuration of wastewater bacteria by shellfish. Results showed that there must be cultureable bacteria in the water to retrieve cultureable bacteria in shellfish. Fecal *Streptococcus* appeared to be a better indicator than total and fecal coliform for correlating bacteria in shellfish with various sources of bacteria.

The Goleta Sanitary District, located in Goleta, California, has completed a series of environmental studies which have investigated bacterial conditions near shellfish mariculture lease sites in the Goleta-Santa Barbara area. The purpose of these studies was to evaluate the potential for wastewater bacteria to contaminate filter feeding shellfish. This paper summarizes the results of these extensive studies which were presented in four reports (Brown and Caldwell 1986, 1987, 1988, 1989).

The Goleta Sanitary District (GSD) provides sanitary services to about 65,000 people. The GSD treatment facilities process approximately five million gallons of wastewater each day. Treatment process include primary clarifiers, trickling filter, solids contact and secondary clarifiers, chlorination and dechlorination. A blended effluent of 3.5 mgd of secondary and the remainder primary effluent is discharged to the ocean 1.6 kms offshore in 27 meters of water.

The City of Santa Barbara's Estero Wastewater Treatment Facility provides secondary treatment for an average daily flow of 9 mgd and discharges this treated wastewater about 14 kms east of GSD discharge in about 24 meters of depth.

Background.—The California Department of Fish and Game has granted five lease areas for shellfish mariculture in the offshore waters between Santa Barbara and Goleta. Some of these leases are used for cultivation of filter-feeding shellfish such as mussels and oysters. In such seafarming operations, mussels and oysters are not grown in their natural habitats (usually rocky intertidal areas or mud flats), but are clustered together and suspended in mesh bags in the water, typically at a depth of 12 meters.

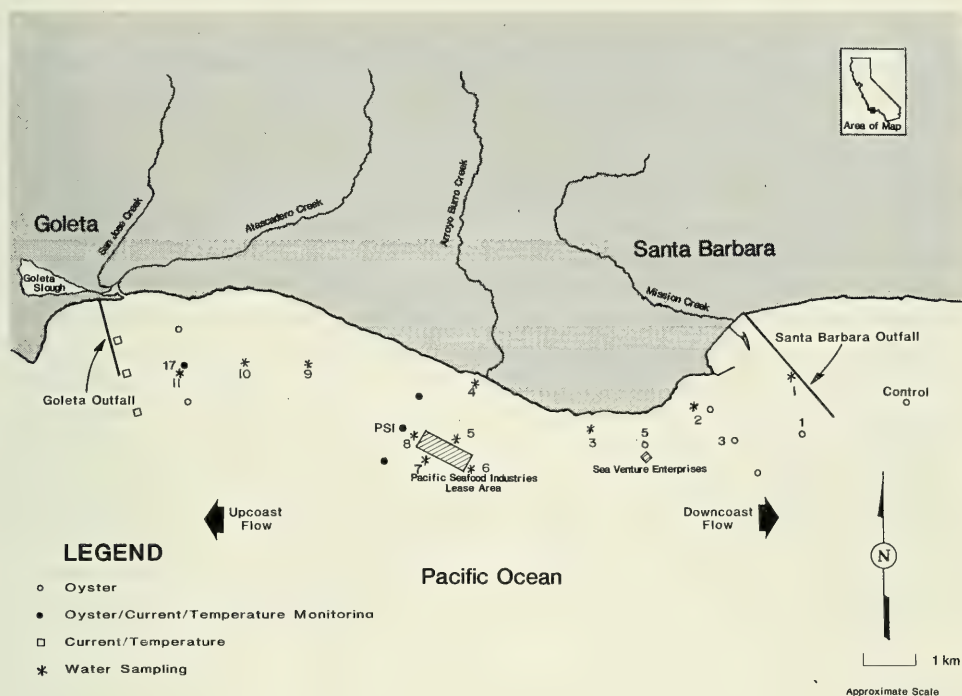


Fig. 1. Study area.

Pacific Seafood Industries Incorporated (PSI) had a seafarming operation located offshore of Arroyo Burro Creek, about halfway between the wastewater discharges of the Goleta Sanitary District, located 7 kms to the West of PSI and the City of Santa Barbara (SB), located 7 kms to the East (Figure 1). In 1985, PSI conducted monthly coliform bacteria analyses of seawater at its' lease area. PSI generally found no coliform bacteria in the water, and where bacteria were detected, their concentrations were within the limits for approved growing waters established by the State of California. Nevertheless, when the oyster meats were tested, four samples exceeded the limit for coliform bacteria. PSI believed that the high levels of bacteria found were caused by the GSD discharge.

When GSD first became aware of PSI's problems, GSD had just begun a extensive study to determine whether its wastewater discharge had any impact on the marine environment. GSD decided to conduct additional studies to determine whether its effluent was specifically affecting bacteriological conditions at the mariculture site.

Study Objectives.—In addition to the extensive ocean monitoring program which was already in progress, a series of environmental studies was initiated by GSD in 1986. The objectives of these environmental studies were: 1) Document the levels and distribution of bacteria found in seawater and shellfish in the Goleta-Santa Barbara area; and 2) Evaluate potential bacteria sources, bacteria die-off rates, and ocean current patterns and other factors which would affect bacteria in shellfish.

For the wastewater field from GSD to affect oysters in the mariculture lease

area, the wastewater plume must be transported to that area before the bacteria in the wastewater field were rendered uncultureable by sea water. Thus, the first stage of these studies evaluated ocean currents and the rate of bacteria mortality in receiving waters.

Methods

Methods used in these studies are described briefly. For a more thorough discussion of methods, see Brown and Caldwell (1986, 1987, 1988, 1989)

Ocean current measurements.—Currents were measured by three InterOcean S4 electromagnetic current meters at several locations throughout the study area (See Figure 1). Currents were generally measured at a depth of 12 meters and were recorded at hourly intervals. Once each hour currents were measured at half-second intervals for a five minute period and an average current, in north and east components was recorded.

Bacteria mortality rates.—Summer and winter studies of the rate of coliform bacteria mortality in the receiving waters were conducted over a 24-hour period. Rhodamine dye was injected into the effluent stream in proportion to flow to create a constant concentration of dye being discharged over a two hour period. Three free-drifting current drogues were placed in the dyed effluent field, one near the leading edge of the dye patch, one in the center of the dye patch, and one near the trailing edge of the dye patch. Water quality and fluorescence profiles were obtained at each drogue location to determine the depth of the wastewater plume as indicated by the peak concentration of dye. In addition to fluorescence profiles, vertical profiles of water temperature, salinity, density, dissolved oxygen, pH, and percent light transmittance were obtained. Water samples were collected from the depth of the wastewater plume as depicted by the water quality and fluorescence profiles and analyzed for total and fecal coliform concentrations by multiple tube fermentations with serial dilutions. Water samples were collected at each of the three drogue locations at approximately hourly intervals over a twenty-four hour period.

Bacteria in seawater.—Water samples from eleven stations arrayed between Goleta and Santa Barbara (Figure 1) were sampled weekly at the surface, mid-depth and near the bottom. These 33 weekly samples were analyzed for total and fecal coliform concentrations with multiple tube fermentation techniques. Samples were collected for a year long period.

Bacteria in shellfish.—Field deployments of oysters and mussels were made during 1987 and again in 1988 at stations shown on Figure 1. During 1987, five deployments of oysters were arrayed along the 24-meter depth contour from 1.6 km east of the City of Santa Barbara's discharge to the Goleta Sanitary District discharge. Oysters were placed in cages consisting of stacked grow-out trays which were suspended in the water column at 12-meter depth with a taunt-line mooring consisting of a dead weight anchor and submerged float. Oysters were sampled every two weeks by retrieving the mooring. Oyster cages were cleaned of biofouling organisms, and dead and decaying oysters were removed from these oyster cages prior to re-deployment. Oysters were kept on ice for bacteriological analyses at Silliker Laboratories. During 1988, additional oyster and mussel deployments were added to provide greater spatial resolution in the onshore-offshore direction to evaluate other potential sources of bacteria.

Laboratory studies.—To supplement field data, laboratory studies of the rate of uptake of bacteria from the water by oysters were conducted. Three exposure tanks and one control tank were used for these studies. Exposure tanks included continuous injection of wastewater effluent (Tank 2), and slug exposures of primary effluent, and chlorinated/dechlorinated primary effluent (Tanks 6 and 7). For the case of continuous injection of wastewater, 100 ml of primary effluent was introduced to a tank containing four-hundred oysters and a continuous drip system using a peristaltic pump added 15 ml of effluent per hour. For tanks 6 and 7, the slug exposures of effluent were introduced to the water two days prior to commencing the experiment. Oysters were placed in static tanks at the beginning of the uptake experiments. Pumps created a circulating current in the cylindrical tanks. Waters and oysters were sampled at 1, 3, 6, 9, 12, 24, 36 and 48 hours after exposure. Water and oyster samples were also collected just prior to commencing the experiment to determine initial conditions. Forty-eight hours into the study, the remaining oysters from Tank 2 were placed in two other tanks with sea water which had not been exposed to effluent. These oysters were used to measurement depuration rates and to determine the effect of dead and decaying oysters on bacteria levels on live oysters. These oysters were then sampled for the following four-day period to determine the rate of depuration of bacteria from oysters.

Results

Ocean current patterns.—Typical results of hourly current measurements are presented as a current rose shown on Figure 2, which presents the relative intensity of current transport in 22.5 degree windows. This magnitude of current transport was determined by multiplying the frequency of occurrence by the speed of currents within the 22.5 degree directional windows. The results of these measurements show the current is upcoast (west) for the vast majority of the time, and flow downcoast toward the mariculture area for less than 10 percent of the time. This current pattern has been documented and reported by many other independent programs in the area including year-long current measurements for ARCO at five locations (Kinetic Laboratories Inc. 1988), 18 months of current measurements for the Mineral Management Service (MMS 1987), and current meter transects for Exxon (Brown and Caldwell in 1989b). Monthly studies conducted for GSD over the past seven years have also shown that currents primarily flow in a westward direction transporting Goleta's wastewater away from shellfish mariculture areas.

This westward ocean transport in the Goleta-Santa Barbara area is due to a large semi-permanent counterclockwise gyre which forms between the mainland and the offshore islands (Brown and Caldwell 1991). This gyre is created by the California current which flows southward along the Oregon-California coastline. The abrupt change in coastline orientation at Point Conception causes a large-scale eddy in the lee of Point Conception as shown in Figure 3. Although reversals in this predominate current pattern occur, they are infrequent and usually have slower current speeds, and are generally insufficient to transport wastewater from the GSD outfall (containing detectable bacteria) to the mariculture area.

Bacteria in ocean water.—There are several sources of bacteria in the marine environment. Large amounts of bacteria are introduced to the nearshore envi-

Station GSD-midshore (1/89-12/92)
34,520 measurements (3.9 years)

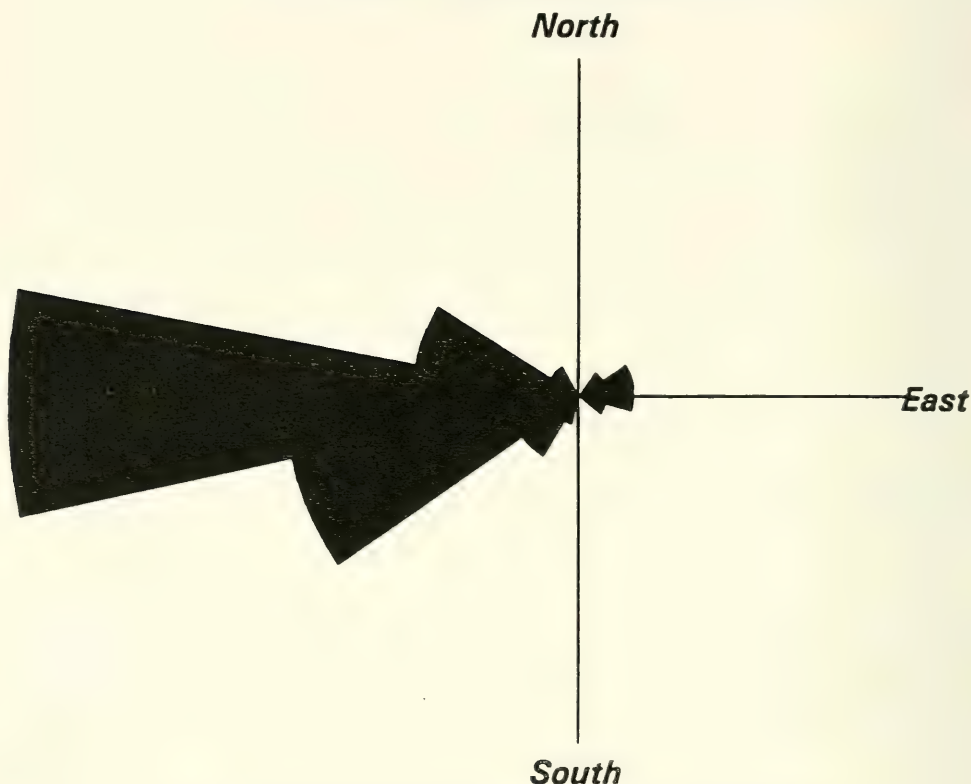


Fig. 2. Relative transport by ocean currents near Goleta outfall.

ronment during periods of stormwater runoff (Jagger 1993). The study area includes several small creeks and Goleta slough. Goleta Slough, Arroyo Burrow Creek, and Mission creek were sampled for total and fecal coliform and standard plate count at six hour intervals during rainfall periods in the last half of 1988. During and following rainfall, large amounts of bacteria reach the coastal environment as the runoff washes bacteria from numerous sources in the watershed (Brown and Caldwell 1989a). The bacterial contribution from local creeks on a rainy day is compared to that from chlorinated discharges for the Goleta Sanitary District and City of Santa Barbara in Table 1. As presented in Table 1, the mass emission of bacteria from creeks during one rainy day exceed the year-long mass emission from disinfected discharges.

These values represent a 1-day contribution of bacteria during a winter storm event on December 17, 1988. The GSD discharge has been disinfected by chlorination since October 1986. The City of Santa Barbara began chlorination in early 1988, and disinfection continues to date except for a 5-week period during the 1988 oyster studies (November 15–December 21, 1988). Hence, data pre-

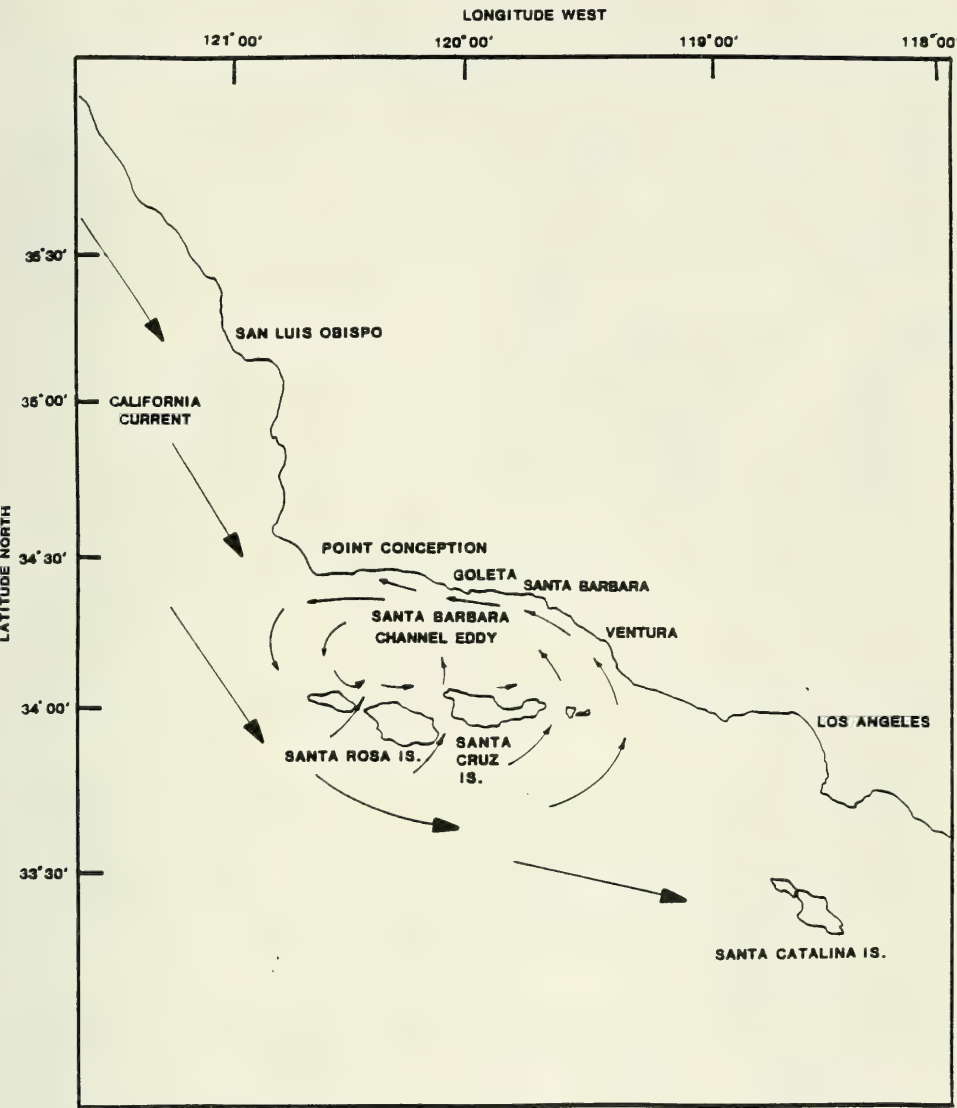


Fig. 3. Santa Barbara Channel ocean circulation.

Table 1. Quantity of bacterial input from local creeks relative to GSD discharge on December 17, 1988.

Location	Quantity
Goleta Slough	43,500
Arroyo Burro Creek	6700
Mission Creek	5900
Santa Barbara Outfall	19.5
Goleta Outfall	1

sented for the Santa Barbara discharge is a geometric mean for the month of December 1988 during chlorination periods only.

Bacteria Mortality Rates: The rate of reduction in concentration of cultureable bacteria in the wastewater after discharge to the ocean environment was investigated during summer and winter conditions in 1986 and 1987. During these studies, non-disinfected (non-chlorinated) wastewater discharged by GSD was marked with a red dye to enable scientists to follow the plume in ocean waters. The results of these studies show that wastewater bacteria become uncultureable at a logarithmic rate of 90 percent reduction in every two hours during the winter with a surfacing wastewater plume and every seven hours during summer conditions with a submerged wastewater field.

Prediction: Based on the ocean current patterns and bacteria mortality rates, we hypothesized that bacteria in the non-disinfected GSD wastewater are not cultureable by the time the wastewater field would be transported to the mariculture site, 7 km to the east (downcoast).

Confirmation: To confirm this hypothesis, an extensive program was conducted during 1986 and 1987 to test ocean water samples for bacteria. More than 3,500 bacteriological analyses were performed on water samples collected weekly at 11 stations in the Goleta-Santa Barbara area. The results of these analyses show that bacteria levels in the ocean water are consistently low or undetectable in the shellfish mariculture area water, except during periods of terrestrial runoff due to rainfall. The water column at the mariculture site consistently met strict standards for approved growing waters (median of <70 total coliform per 100 ml and <14 fecal coliform per 100 ml).

Bacteria in caged shellfish.—Although waters at the shellfish mariculture area consistently met standards for approved growing areas, bacteria in shellfish meats sometimes exceeded standards for human consumption (>230 fecal coliform/100 g). Since the concentrations of bacteria found in the maricultured shellfish did not correlate with the concentrations found in the ocean waters, studies which measured shellfish bacteria directly were initiated. Two similar studies were conducted in 1987 and in 1988.

These two studies analyzed bacteria in shellfish which had been stationed in mariculture cages at several locations along the Goleta-Santa Barbara coast (Figure 1). The station array included oyster cages deployed between the GSD discharge (Station 17) and the SB discharge (Station 1). Station PSI and Station 5 were located adjacent to the shellfish mariculture operations of Pacific Seafood Industries and Sea Venture Enterprises, respectively.

The studies were conducted from July to December to minimize the bacterial influence of stormwater runoff so that the effect of wastewater discharges could be studied specifically. The offshore studies in 1987 were somewhat affected by rainfall, with rain in late October, November, and December, 1987. The stormwater runoff from creeks contains significant amounts of coliform bacteria (Brown and Caldwell 1989b) and consequently affected bacteria levels in oysters during some 1987 surveys. In 1988, the first significant rainfall and stormwater runoff event occurred in December at the end of the field sampling program, thus 1988 data were not affected by bacteria in stormwater runoff.

Results of these two studies are summarized in Figure 4, which presents the percent of time that fecal coliform levels exceeded the maximum allowable con-

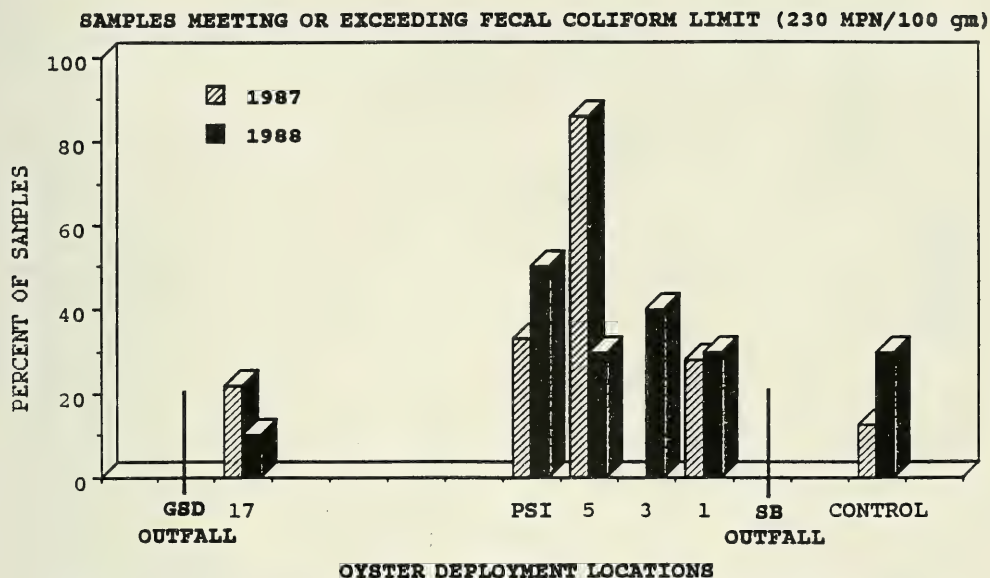


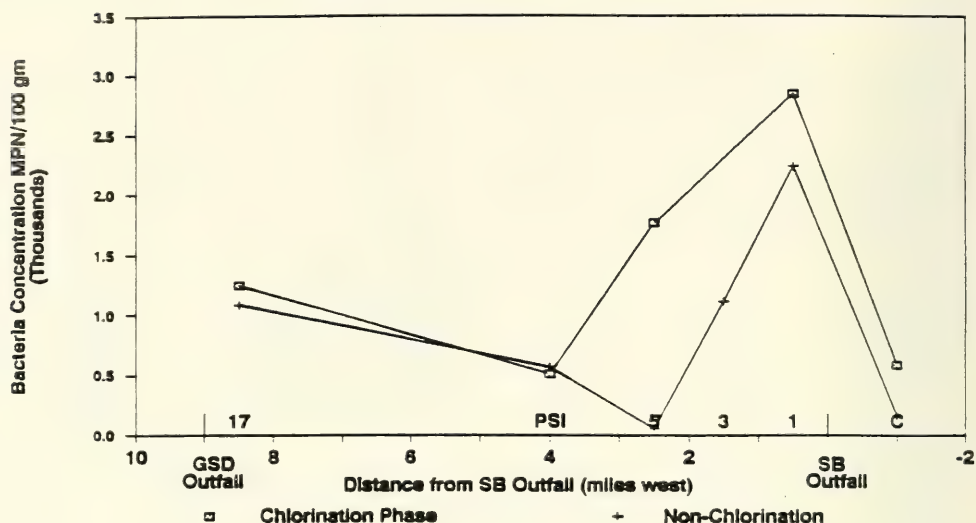
Fig. 4. Percent of time oyster meat tissue bacteria levels exceeded fecal coliform standards.

centration for human consumption in shellfish meats at the six stations arrayed between Goleta and Santa Barbara.

Data from both years show similar trends with the highest percent of samples exceeding the shellfish standards occurring near the center of the study area, and not near the wastewater discharges of GSD and the City of Santa Barbara nor terrestrial sources of Goleta Slough and Mission Creek. For 1987, the highest number of samples that exceeded shellfish standards occurred at Station 5 adjacent to the Sea Venture Enterprise lease area. During 1988, Sea Venture had no shellfish deployed, and the highest percent exceeding shellfish standards occurred at the PSI lease area. Major differences between the 1987 and 1988 studies were that Sea Venture Enterprises' mussels were not deployed in 1988 and the City of Santa Barbara was disinfecting during 1988, except for a 5-week hiatus designed to assess the benefits of chlorination.

Figure 5 presents data for SB discharge chlorination and nonchlorination periods during upcoast current periods of the 1988 study. Surprisingly, total and fecal coliform bacteria were higher in shellfish meat tissue during periods when SB was disinfecting its wastewater (chlorination) than during periods of non-disinfection (no chlorination). Similar results were also reported during the study conducted for the City of Santa Barbara (Ecomar 1989). Data from upcoast current periods show that the Santa Barbara discharge may have affected Stations 1 and 3 located 0.8 and 2.4 kms upcoast of the discharge, respectively, but did not affect stations further away. Within 4 kms of the discharge (Station 5), bacteria in the oysters were below the background levels at the control station. Therefore, the City of Santa Barbara's discharge did not affect shellfish at PSI, whether the effluent was disinfected or not. Certainly the GSD disinfected discharge was not affecting oysters at PSI during these upcoast periods, and shellfish bacteria levels at Station 17 were the lowest of all sampling stations.

TOTAL COLIFORM BACTERIA



FECAL COLIFORM BACTERIA

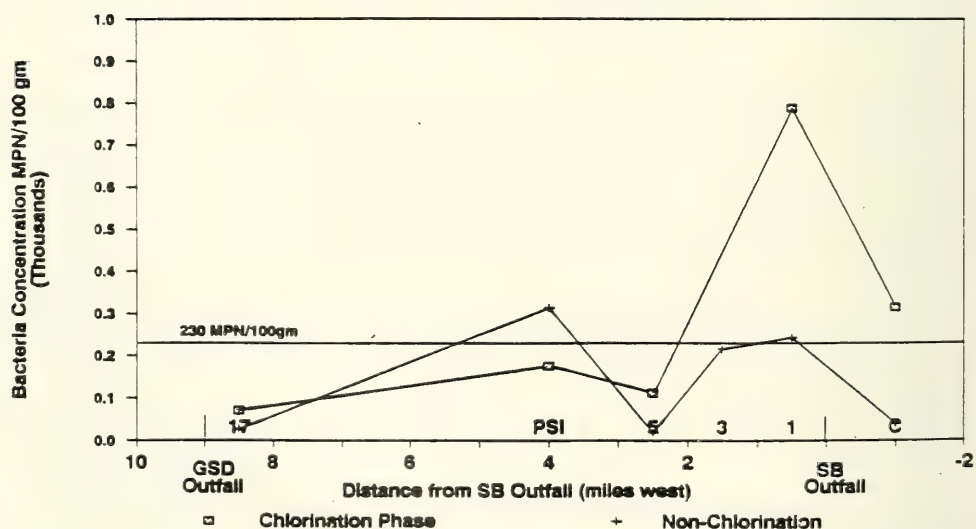


Fig. 5. Coliform bacteria concentrations during upcoast currents for chlorination and nonchlorination periods at the City of Santa Barbara Wastewater Treatment Plant.

Cross-shelf oyster station arrays were used to determine the effect of stormwater runoff from local creeks. These arrays were established at Stations 3, PSI, and 17. Each array consisted of oysters deployed at three locations extending offshore at water depths of 12, 24, 36 meters. The nearshore stations at 12 meters of depth had higher bacteria concentrations than stations in 24 and 36 meters of water for transects through Station 3 and Station 17, but the inshore 12-meter station near

Table 2. Total bacteria content in seawater and oysters of each uptake experiment tank.

	Tank 2 (continuous injection undisinfected effluent)	Tank 6 (aged undisinfected effluent)	Tank 7 (aged chlorinated & dechlorinated effluent)
Bacteria introduced to tanks (on a per oyster basis)			
Bacteria introduced			
Total coliform	2,050,000	11,360,000	57,000,000
Fecal coliform	205,000	1,136,000	5,700,000
Fecal streptococci	20,500	113,600	570,000
Culturable bacteria			
Total coliform	34,850	197,200	1,710,000
Fecal coliform	4,510	25,250	199,500
Fecal streptococci	615	3,480	17,100
Culturable bacteria recovered from oysters (per oyster)			
Culturable bacteria			
Total coliform	53	24	439
Fecal coliform	30	13	11
Fecal streptococci	24	28	35

Arroyo Burro Creek had similar bacteria concentrations to Station PSI. These data indicate that Goleta Slough and nonpoint source runoff can affect offshore shellfish mariculture areas. Arroyo Burro Creek did not appear to have as much impact as Goleta Slough.

Stormwater Sampling.—In addition to the extensive field studies conducted with shellfish during 1988, Goleta Slough, Arroyo Burro, and Mission creeks were sampled for bacteria at 6-hour intervals during storm conditions for the months December 1988 through March 1989. These stormwater runoff samples typically contained tens of thousands of coliform bacteria per 100 ml. During the wet weather season, these streams are the largest source of coliform bacteria introduced to the study area.

Laboratory Experiments.—Laboratory experiments were conducted to assess the rate of bacterial uptake and depuration by oysters in sea water mixed with wastewater effluent. During bacterial uptake studies, oysters exposed to low water concentrations of bacteria by a continuous injection of effluent in one tank had low concentrations of recoverable bacteria from the meat (<100 fecal coliform per 100 g). In two other static tanks, large numbers of cultureable bacteria were introduced to sea water and allowed to become uncultureable over a two day period and then oysters were placed in these tanks. These experiments showed that cultureable bacteria were not recovered from oysters placed in these tanks. Results of these studies show that oysters which were subjected to high numbers of bacteria did not show similar elevations in tissue bacteria levels. Table 2 summarizes the total amount of bacteria detected per oyster for each tank and the number of bacteria introduced to the tank on a per oyster basis. Although the oysters in all three tanks were exposed to seawater with over one million coliform

bacteria for a 2-day period, the oysters generally assimilated fewer than 60 MPN total coliform bacteria in their meats.

Summary

Extensive marine investigations conducted throughout the Goleta-Santa Barbara area indicate that wastewater discharged by the Goleta Sanitary District and the City of Santa Barbara does not adversely impact the shellfish near the mariculture area. The 1988 data indicated that the high bacteria levels at shellfish mariculture lease areas were induced by terrestrial runoff in the immediate vicinity during rainy periods, and by local environmental conditions at the mariculture site itself, and were not caused by wastewater discharges.

The results of the 1987 and 1988 shellfish studies showed a correlation between the number of dead shellfish in the mariculture cages and the concentration of bacteria in the shellfish tissue. These decaying shellfish, which are known to contain high levels of bacteria, may contribute to higher bacteria concentrations in healthy shellfish in the same cages.

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Succession and the Role of Ophiuroids as it Applies to the Marine Infaunal Associations off Palos Verdes, California

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Abstract. —Based on literature and data from monitoring surveys throughout the Southern California Bight and especially off Palos Verdes, the pattern and rate of succession of ophiuroid populations of a previously perturbed (ocean outfall) area is assessed. Pre-discharge population levels of ophiuroids off Palos Verdes were generally low, and between the early 1950's and 1970's densities were near zero. From 1972 to 1992 the number of ophiuroid species and densities have increased towards the center of the shelf and the zone of initial dilution (ZID), previously impacted by the effects of outfall. Even after natural mass mortalities, resettlement of ophiuroid populations is very slow, mainly due to adult migration rather than larval recruitment. In turn, the presence of high densities of adult populations favors settlement and metamorphosis of larvae. Conditions suitable for promoting and maintaining critical levels of adults represent the Catch-22 of larval recruitment, and hence successful resettlement of a previously perturbed area. Regardless, conditions for infaunal benthos in general, and ophiuroids in particular, continue to improve off the Palos Verdes outfall as resettlement progresses.

This report focuses on the concept of succession as it relates to ophiuroids in soft-bottom marine habitats. Data from the literature and from monitoring programs are used to determine the pace of repopulation by ophiuroids of a previously impacted area (Palos Verdes outfall). Finally, the rate of return is examined to determine whether it is consistent with the biology of the regionally dominant species, and with prior studies of sites where the source of disturbance has ceased.

The Concept of Succession

Succession is one of the oldest concepts in ecology stemming from work on terrestrial plant communities at the turn of the century. Although other workers preceded him, Clements (1936) is commonly recognized for giving it vigor and status. He assigned traits of individuals (orderliness, direction, predictability) to succession in communities and fostered the idea of all communities moving towards a known end (climax sere) or final successional stage. According to this notion for each habitat type there was a single predictable end point. Other workers commented on the universality and simplicity of succession and defined it as the orderly process of community change (Odum and Odum 1959). However, even then it was recognized that natural exceptions to the orderly process occur, as the Odums cited natural situations in which the expected climax state was never reached.

Lindeman (1942) added new components to the concept by emphasizing interactions between organisms and the environment as these contribute to a rel-

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atively stable condition of equilibrium. This notion emphasizes that early successional species modify the environment in ways that prepare it for later successional species. This process came to be known as facilitation.

More recent literature challenges the properties of stability and equilibrium and whether facilitation or its counter part, inhibition is the driving successional force (Connell and Slayter 1977; Gallagher et al. 1983). The concept of succession evolved greatly over the past quarter century, when natural or anthropogenic disturbance was promoted as basic to the resulting change. One revision defines succession as changes in an ecological community following a perturbation that opens up a relatively large space (Connell and Slayter 1977). Although not without critics, this definition deals with short term (not evolutionary) succession, responses by component populations to trends and cycles in physical/chemical parameters, biological interactions and life history traits, following a disturbance to an existing community. Their definition does not refer to predictability, to orderliness or to a single climax state as the end point. The following section considers the parameters that lead to multiple paths and multiple end points that are commonly recognized as applying to marine soft-bottom benthos.

Succession in the Marine Environment

The development of quantitative soft-bottom communities is associated with northern European researchers, most notably Petersen (1911, 1918) and Thorson (1946a, 1957). This research had a practical bent as the status of benthos as flatfish diet was used to predict future stocks of demersal fish. An important by-product of this approach led to the practice of naming marine communities after characteristic species (ophiuroids, bivalves, polychaetes). This practice emphasized the predictability of community composition. Thorson (1955) initially promoted the concept that level bottom communities in the same depth and substratum and at similar latitudes all over the world would all harbor similar characteristic species types. This concept yielded to multiple community types as more samples were taken in more locations including the tropics (Thorson 1966; Gray 1981; Alongi 1990). Thorson (1955) recognized a variety of factors that influenced species survival and colonization. Grain size and water temperature together with competition, predation and life history parameters were cited. His list is not all inclusive and the next section will cover factors linking succession to soft-bottom marine communities (physical habitat, facilitation, inhibition, interference, life history, time, scale in area of disturbance, chance).

Factors Controlling Succession: Habitat

For soft-bottom benthos on open continental shelves, principal habitat parameters are depth, granulometry, nutrition sources other than other organisms, dissolved oxygen, light, currents, temperature and pressure (Hedgpeth 1957; Kinne 1970; Gray 1981). So many parameters covary with depth that it is a dominant source of variance in accounting for local distribution of species in subtidal marine habitats. This certainly is the case in the Southern California Bight (Thompson et al. 1987). Depth on the shelf influences the extent and frequency of disturbances of bottom sediments from translated wave energy which in turn affects granulometry.

Sediment grain size may directly affect the suitability of a habitat for coloni-

zation and indirectly affect habitat suitability through its effect on organic content, pore water content and circulation in the sediments, all of which affects dissolved oxygen in the sediments (Gray 1981; Rhoads and Boyer 1982). Finer grained sediments are associated with higher organic carbon contents and facilitate less pore water circulation leading to lower dissolved oxygen and higher levels of H_2S production. Although many species of soft-bottom benthos avoid areas of low dissolved oxygen (Gaston 1985), some species have evolved considerable sulfide tolerance, and even settle preferentially under conditions of low oxygen and high H_2S production (Chesney 1984; Vismann 1991). The larvae of these latter species are capable of using this chemical cue for exploiting high detrital organic food sources, and would be more likely to participate in successions in such habitats. Adults of other species respond to organic gradients by migrating towards or away from the source of enrichment (Pearson and Rosenberg 1978; Muscat 1983).

Hydrodynamic processes for larval transport vary greatly, but they may be very influential in influencing local succession (Butman 1987; Pedrotti and Fenaus 1992). In addition, the presence of sufficient near bottom water motion favors maintenance of infaunal suspension feeders (Buchanan 1964; Buchanan and Moore 1987). Coupled with hydrodynamic processes, temperature is one of the more important factors governing the geographic range over which species are distributed (Kinne 1970). Water temperature may also be an important stimulus to precipitate a new round of reproduction, spawning, and hence succession (Gerdes 1977). Pressure is the one parameter which varies with depth, but within the range of shelf and upper slope depths, pressure does not appear to significantly control invertebrate population distributions. Pressure indirectly affects invertebrate populations by directly influencing predation of fish with swim bladders.

Mechanisms by which physical parameters act on succession are reviewed by Gray (1981) and Rhoads and Boyer (1982). Perturbation may drive local species to azoic levels, but in moderate cases leave those species most tolerant of changes. Species from surrounding habitats tolerant to conditions in the disturbed area may immigrate. Opportunists will also add to the successional pattern. Increased population sizes will make biological interactions more influential. The resulting assemblage will represent the overlap of regional species preference gradients, and their timing and ability to establish themselves among others with similar habitat preferences.

The size and frequency of disturbance with increasing depth will affect the rate of succession and relative importance of immigration and larval settlement in controlling early species composition and dominance (Van Blaricom 1978; Bonsdorff and Osterman 1984; Petraitis et al. 1989). Accordingly, large disturbed areas at the edge of the shelf would take longer to recover than shallower nearshore areas with smaller acreage of disturbance.

Factors Controlling Succession: Biological Mechanisms

Facilitation describes a mechanism in which species modify the habitat, making it more attractive to later arriving species. At Palos Verdes the echiuroid worm *Listriolobus pelodes* had a major effect on succession by its reworking of near surface sediments (Stull et al. 1986). Infaunal tube builders have demonstrated similar affects on the composition of later arriving settlers. Study of the influence

of biogenic structures and activities on colonization has produced an extensive literature (Clinton and Woodin 1993).

Inhibition describes a mechanism in which species discourage or prevent recruitment of new species (Connell and Slayter 1977). Moreover, opportunists once established, suppress later return of pre-disturbance species. Major events in the inhibition process produce patches allowing later successional species to invade the confines of early benthic stages. Once the later stages become established, competition and predation by these species can prevent the return to dominance by earlier stage species. This variation of inhibition is termed interference.

Life history strategies of both early and late stage invaders play a major role in the direction and timing of succession. Adult longevity, motility, plasticity of habitat tolerance, brooders vs. broadcasters, fecundity, larval duration are some of the life history properties influencing recruitment and succession.

Factors Controlling: Time, Space and Chance

Time influences succession at a number of scales (annual, seasonal). Timing of the disturbance in relation to the availability of recruits strongly influences which species will be involved in colonization and the ensuing stage of succession (Gray 1981). Return of species to defaunated patches may take only hours to months for small patches (Thistle 1985).

Where the disturbance is recurring, stable community structure measures (number of species, abundance) may never be reached. Where the size of the disturbance area is large, several years may be required to return to pre-disturbance community levels. Bonsdorff (1982) reported that six years after cessation of dredging in a shallow soft-bottom benthic habitat, there was only a 65% similarity of species in the effected area with controls. Gray (1981) concluded that while early stages of succession are generally predictable, the middle and later stages are neither predictable in time of their duration or their species compositions. Connell and Slayter (1977) state that succession in natural communities proceeds along different paths, at different rates to a range of multiple stable points within the same habitat.

Many early opportunistic species (*Capitella* spp.) are not excluded from later successional stages, but are relegated to low densities by interactions with later successional species (Chesney 1984). Short generation times and short or absent larval dispersal times for opportunists favors them to rapidly dominate new larger patches. Under natural conditions, multiple species composition states exist which can be moving in more than one direction at the same time in different patches.

Stochastic events may destabilize natural assemblages, leading to the chaotic rise of normally rare species to temporary dominance (Chesson 1978; Vandermeer 1982). The juxtaposition of quasi independent physical factors, independent set of species, independent suite of life history variables makes the prediction of the ensuing species composition of an area (>1000 species for the Bight) very uncertain.

The Biology of Ophiuroids in Relation to Succession

Ophiuroids are echinoderms found in all marine habitats, from the intertidal to the deepest ocean depths, and from the shallow tropics to the Arctic, on hard

bottoms and soft ones. The general biology of ophiuroids is reviewed in Fell (1946, 1966) and Hyman (1955).

Smidt (1951) examined habitat suitability for large numbers of ophiuroid larvae, but without any subsequent recruitment. He found larval densities in the flood tide plankton exceeding $150/\text{m}^3$ in a northern European estuary, and one of the three common species was observed to metamorphose and settle, but no post-juveniles were obtained in grab samples. Based on plankton counts and the competent stage of the ophiuroid larvae, one would expect a relatively high degree of metamorphosis, settling and recruitment. However, some of the complex of factors so necessary for recruitment and succession provided an unsuitable habitat.

Buchanan (1963, 1964) found good correlations with depth, temperature and grain size for two species of ophiuroids. *Amphiura filiformis* (suspension feeder) required a minimal water current to provide suspended particulates. These conditions prevailed in shallower water producing a coarser sediment surface, but also coexisting with warmer water temperatures. The apparent correlation with grain size, depth and temperature was probably more related to near bottom currents. *Amphiura chiajei* (deposit feeder) preferred finer sediments with a greater concentration of organics at increasing depths. Granulometry may have little direct influence on the suitability of habitats for some ophiuroid species (Ursin 1960; Lie 1968).

Although ophiuroids feed on other infauna (polychaetes, crustaceans, larval and juvenile pelecypods), most are detrital feeders reacting positively toward organic content (Hyman 1955). Density of *A. filiformis* increased from 100 to $300/\text{m}^2$ with the addition of sewage source organics to natural sediments (Buchanan and Moore 1987). Ophiuroid populations can increase in sewage enriched sediments which do not approach anoxic levels (Pearson 1975).

Ophiuroids are relatively long lived (8–15 yrs) with some living only three or four years (Buchanan 1964; Fell 1966). Most have multiple spawns during long breeding seasons for several years, producing large numbers of planktonic larvae (Hyman 1955; Thorson 1946a, b). The irregularity of recruitment of ophiuroids despite the presence of seemingly suitable habitats and high densities of larvae and adult populations has been frequently documented (Thorson 1946a, b). Long-term studies have shown great annual variations between high densities of adults and successful larval sets, with sporadic setting, and as much as a five year hiatus between successful sets (Ursin 1960; Buchanan 1967; Muus 1981). One long-term study demonstrated that immigration by adults, rather than recruitment from plankton despite the availability of larvae, was responsible for maintaining relatively high population densities (O'Connor et al. 1987).

With suitable habitats where adults are present lack of recruitment may result from inhibition, and especially by predation on juveniles and larvae (Thorson 1946a, b; Gerdes 1977). There is a high rate of predation by flatfish on ophiuroids (Jones 1952; Buchanan 1964). Juveniles are very vulnerable until their arms grow long enough to provide adequate cover by deeper burial. Allen's (1982) studies on the diet of fish feeding guilds off Palos Verdes, California supports predation by demersal fish on ophiuroids. Off the Orange County California ocean outfall, a barred sand bass was caught in July, 1993 with its mouth and stomach full of ophiuroids (*Ophiuria lutkeni*) (Tom Gerlinger, personal communication).

Chemical cues for the attraction of larvae are known for many marine inver-

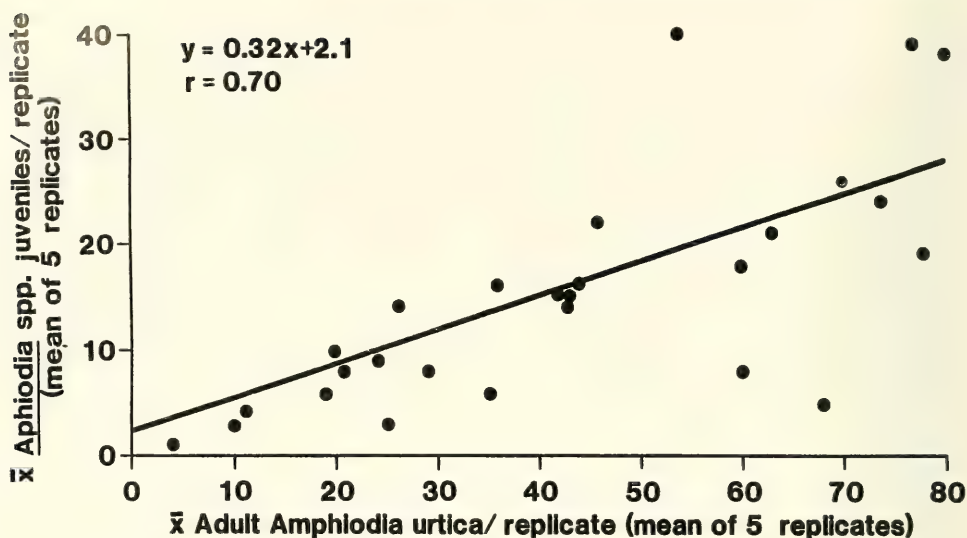


Fig. 1. Relationship of juvenile to adult ophiuroids off Orange County.

tebrates (Morse 1990; Pearce and Scheibling 1990). Where adults are present, there may also be facilitation of larval settlement by chemical or tactile signals. The common association of juvenile ophiuroids with large numbers of adults has been known for a long time (Hyman 1955). This relationship was tested in the Southern California Bight. Based on samples collected from the ongoing Orange County 301(h) monitoring program (seven quarterly surveys from August 1985 through January 1987 for stations C, 5, 13, and Con), there were no occurrences of juvenile *Amphiodia* spp. in the absence of adult *Amphiodia urtica*. When the mean number of juvenile *Amphiodia* spp. were regressed against adult abundance of *Amphiodia urtica*, a regression coefficient of 0.70 was completed (Fig. 1). This quantitative analysis supports the proposition that the presence of adult ophiuroids fosters successful recruitment of their respective larvae. This relationship should be examined with similar data sets throughout the Bight and through experiments with ophiuroid larvae (in this case *Amphiodia urtica*).

In the following section I focus on studies which deal specifically with the slow pace of ophiuroid resettlement. After the cessation of organic enrichment in a northern European embayment, the rate of resettlement of *A. filiformis* and *A. chiajei* was charted. During five years *A. filiformis* had moved less than halfway back into the bay ($\cong 3$ km/5 yrs) and *A. chiajei* $\cong 1$ km/5 yr (Rosenberg, 1973). Both of these rates suggest a rate of adult immigration rather than larval recruitment because other non-opportunistic species resettled the bay much more rapidly than the ophiuroids.

A population of *A. filiformis* was wiped out by a particularly cold winter in the inner German Bight (Gerdes 1977). With a known large source population 50 km distant, no recruitment was seen for four years under intensive sampling. Initial recruitment levels were at a density of 3/m², and by the end of the first summer, the population was again undetectable. Winter of the following year yielded den-

sities of $3/\text{m}^2$, still an order of magnitude below pre-disturbance (winter mortality) conditions.

Caspers (1980) showed that ophiuroids could resettle and become dominants in habitats high in TOC of sewage origin with very fine sediment grain size, after remission at anoxic conditions, and initial runs of opportunists. Finally, over the three year course of an experiment with controls and defaunated sediment traps, ophiuroid densities in the traps never reached control densities (Arntz and Ruhmohr 1982) compared to $12/\text{m}^2$ for controls, ophiuroids remained at 1 to $3/\text{m}^2$ in test sediment. Coincidental with these results community measures (number of species, abundance) in test sediments conformed to controls. These four studies support the proposition that resettlement by ophiuroids can be a very slow process both through adult migrations and larval recruitment.

Ophiuroids in the Palos Verdes Area

Common soft-bottom, California shelf and slope species belong mainly to the genera *Amphiodia*, *Amphipholis* and *Amphioplus* with *Amphiura*, *Amphichondris*, *Ophinera* and *Ophiurocous* being less frequently encountered (Barnard and Ziesenhenné 1961). Between 1953 and 1954 *Amphipholis* and *Amphioplus* dominated depths less than 37 m and *Amphiodia* 37 to 55 m (Hartman 1966). This depth range is consistent for these genera with *Amphipholis* and *Amphioplus* preferring sediments with about 50% silt and clay and *Amphiodia* 80% (Barnard and Ziesenhenné 1961).

Prior to the start of the Los Angeles County Sanitation Districts' (LACSD) monitoring program in 1970, *Amphiodia*, *Amphipholis*, *Amphioplus* and *Ophiothrix* occurred near the County's transect numbers 0, 1 and 2 (Fig. 2) in 1953 and 1954, and between transects 1 and 2 and near 4, 6, 7, and 8 in 1957 and 1958 (Hartman 1955; State Water Quality Control Board (SWQCB) 1965). Near transects 4 to 8 ophiuroids were only reported in 18 to 25 m, but none were recorded from clean fine sediments near transect 10 by either Hartman or SWQCB.

According to the regional view by Barnard and Ziesenhenné (1961), the dominance (abundance and frequency of occurrence) of *Amphiodia* spp. stopped near Palos Verdes Point and did not assume importance again until in the vicinity of Newport Canyon. This distribution coincides with the fine olive green sandy silts which pinches out at Palos Verdes. The area south of Pt. Fermin consists of medium to coarser sands on the San Pedro shelf extending to Newport, and coincidentally favors the dominance of *Amphipholis* spp. The steep slope at Palos Verdes compared to that either north or south of it leaves a relatively narrow band of potential habitats (sediment type) for these two genera. Regardless, these two genera and others were reported as present in the 1990's (Hartman 1955; SWQCB 1965).

Based on monitoring data from the LACSD program off Palos Verdes, the number of ophiuroids for all samples, average number per sample, the maximum recorded density and the transects where observed are presented (Table 1). For all categories there was a definite increase from 1972 until 1986. The decline in 1980 is similar to the range of natural population fluctuations noted for ophiuroids elsewhere (Gerdes 1977). For the period 1972 to 1986 the occurrence of ophiuroidea on the Palos Verdes shelf shows a clear trend toward reestablishing ophiuroid populations outside the zone of initial dilution (ZID) near the White's Point

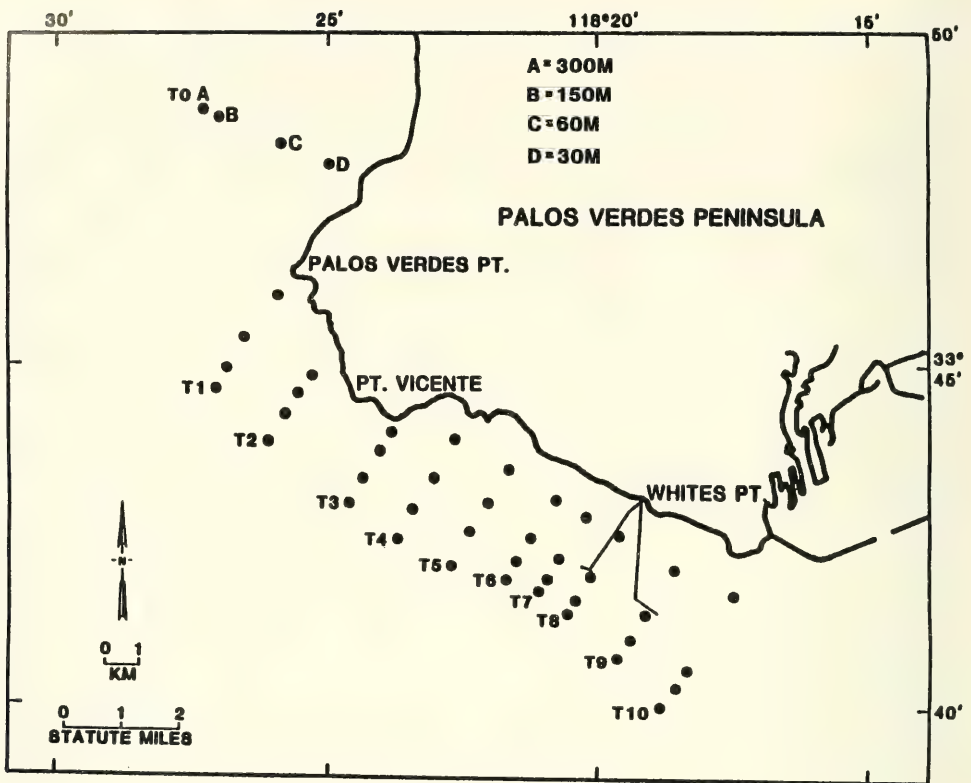


Fig. 2. Location of outfalls and landmarks in Palos Verdes area.

outfall (LACSD) (Fig. 3). Another figure only representing abundance of *Amphiodia* spp. from 1972 to 1992 shows this taxon encroaching on the ZID (Fig. 4). A similar trend of resettlement by *Amphiodia urtica* near (30 m) an ocean outfall (CSDOC) has been recorded (Gerlinger et al. 1993). Thompson's (1987a, 1991) account of benthic recovery from cessation of sludge discharge in Santa Monica Bay indicates a similar pattern.

Prior to speculating on the causes of the slow rate of return of ophiuroids to the Palos Verdes area, the 1977 Southern California Coastal Water Research Project (SCCWRP) reference survey (0.1 m² grab samples along 60 m isobath) from Point Conception to the Mexican border is germane. The survey recorded a single ophiuroid near the County's transect 0 (Fig. 2), three species and eight individuals near 10, none between 2 and 3, or between 5 and 6 (Word and Mearns 1979). These data are consistent with those reported in Table 1 and Fig. 3. The same survey sampled 11 stations (Station numbers 37-47) between Pt. Fermin and Newport and recorded one or two species per sample and a mean density of <10/m² from those San Pedro Shelf stations. Two of the stations toward the southern end of that series had no ophiuroids. This survey indicates considerable regional variation in ophiuroid species occurrences and abundance throughout the Bight. Moreover, the reference survey data depict lower natural ophiuroid densities than presently occur off Palos Verdes (Fig. 3-4) (Thompson et al., 1987).

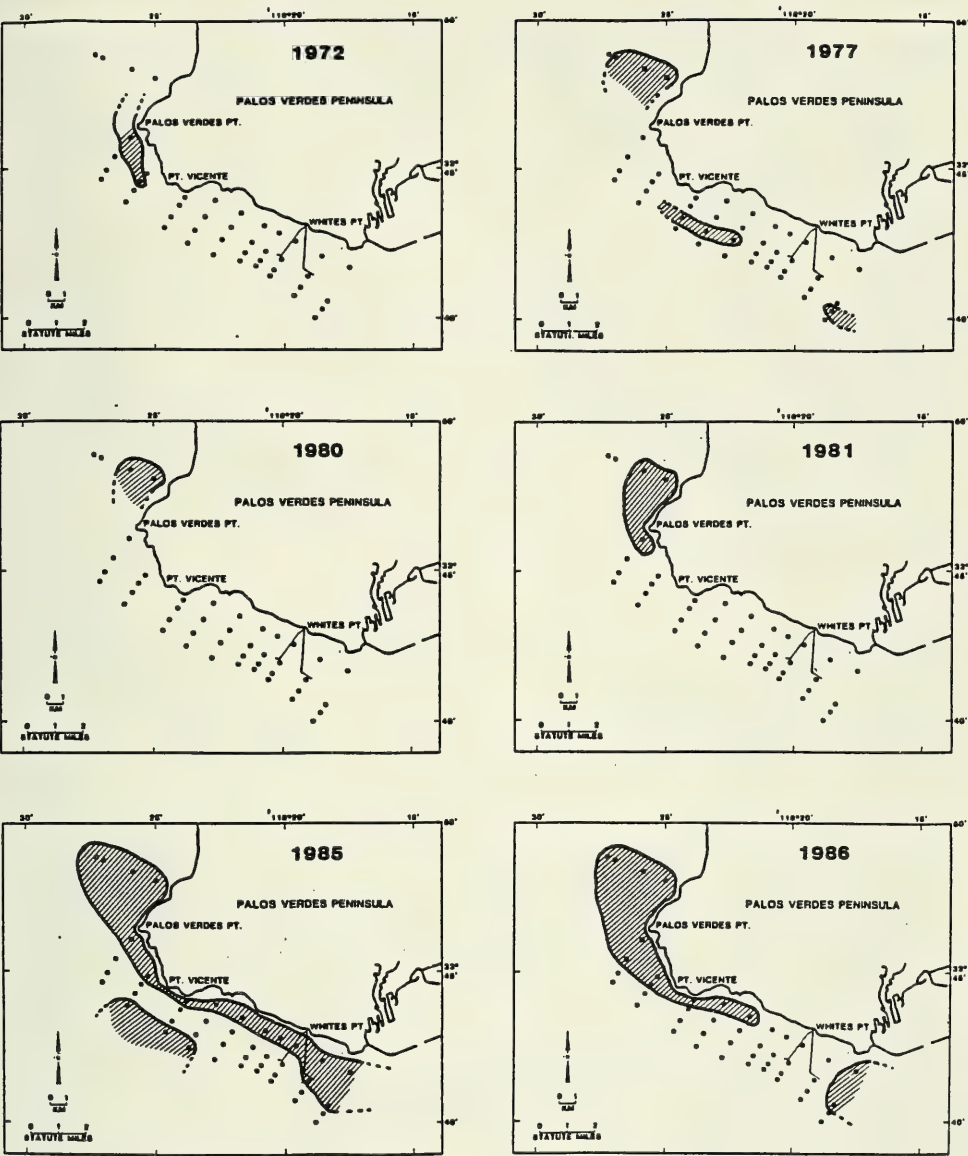


Fig. 3. Comparative distribution-occurrence of Ophiuroidea 1972–86.

Factors Likely to be Contributing to a Slow Ophiuroid Recruitment

Between the early 1950's and the early 1970's ophiuroid densities declined to near zero on the Palos Verdes shelf. Since then they have been slowly returning (Fig. 3, 4). There are no available pre-discharge samples off the LACSD outfall to provide an accurate estimate of what original or natural densities were like, or which species occurred. However, samples peripheral to, or marginal to the outfall indicate that species composition and density were comparable to, or probably less than recent data indicate as being present (Hartman 1955; SWQCB 1965;

Table 1. Distribution and abundance of ophiuroids off Palos Verdes.

Year	Total counts ^a	Average ^b density	Maximum ^c density	Transects ^d where observed
1972	3	30	30	1, 2 ^e
1977	10	40	60	0, 3, 6, 7, 10
1980	8	45	60	0
1981	26	53	90	0, 1
1985	129	65	300	0, 1, 2, 3, 4, 6, 7, 8, 9, 10
1986	150	95	520	0, 1, 2, 3, 6, 10

List of species included in the above listed occurrences: *Amphichondris granulatus*, *Amphiodia* spp. (3 species); *Amphioplus hexacanthus*; *Amphipholis* spp. (2 species); *Amphiura arcystata*; *Ophiuroconis bispinosa*.

^a Counts of all ophiuroids from all samples in that year; aggregate sample size per station was somewhat larger in 1972 than later years.

^b Total count divided by the number of samples containing at least one ophiuroid (i.e., frequency) and converted to n/m².

^c The highest single sample count (or aggregate replicate count per station for early shipek samples) converted to n/m².

^d See Figure 1 for transect locations.

^e No transect 0 samples collected in 1972.

Word and Mearns 1979; Thompson et al. 1987). Several questions emerge: How much further into the center of the Palos Verdes shelf will ophiuroids penetrate, and how long will this process take?

Because of the large area initially depressed several years will be required to show signs of new ophiuroid settlers or immigrants at distances as little as one to five km from the margins (Rosenberg 1973). Such returns and more have already occurred (Figure 3, 4). Despite a sediment granulometry and food supply that should be conducive to *Amphiodia* spp. the lack of high density adult populations may be failing to cue the settlement of their larvae in sufficient numbers to overcome the competition and predation of bivalves and other feeders, and the predation of flatfish, particularly dover sole (Allen 1982). A sediment bioassay from LACSD Station 7C (Fig. 2) provided no evidence of acute toxicity to adult *Amphiodia urtica* (Thompson 1987b). The same species was challenged with sediment containing elevated levels of contaminant from a 60 m station from Newport Canyon and the Orange County outfall. Results from a preliminary pilot study showed no acute toxicity under these conditions as well (Tom Gerlinger, personal communication).

These factors combine to suggest that ophiuroids will eventually resettle in the center of the shelf mainly through immigration of adults. Based on the distances remaining, slower expected pace at greater depths, and natural biological interactions to accommodate, another five years would be a good estimate of the time to find ophiuroids being reported for essentially all non-ZID stations. (Editors note: Dr. Scanland made this prediction in 1987, data depicted in Fig. 4 through 1992 certainly are consistent with his estimate).

Conclusions

Succession in marine soft-bottom habitats of shelf and upper slope depths is a highly complex process. The species composition, number of species and abundance of the assemblages from a previously disturbed area cannot be accurately

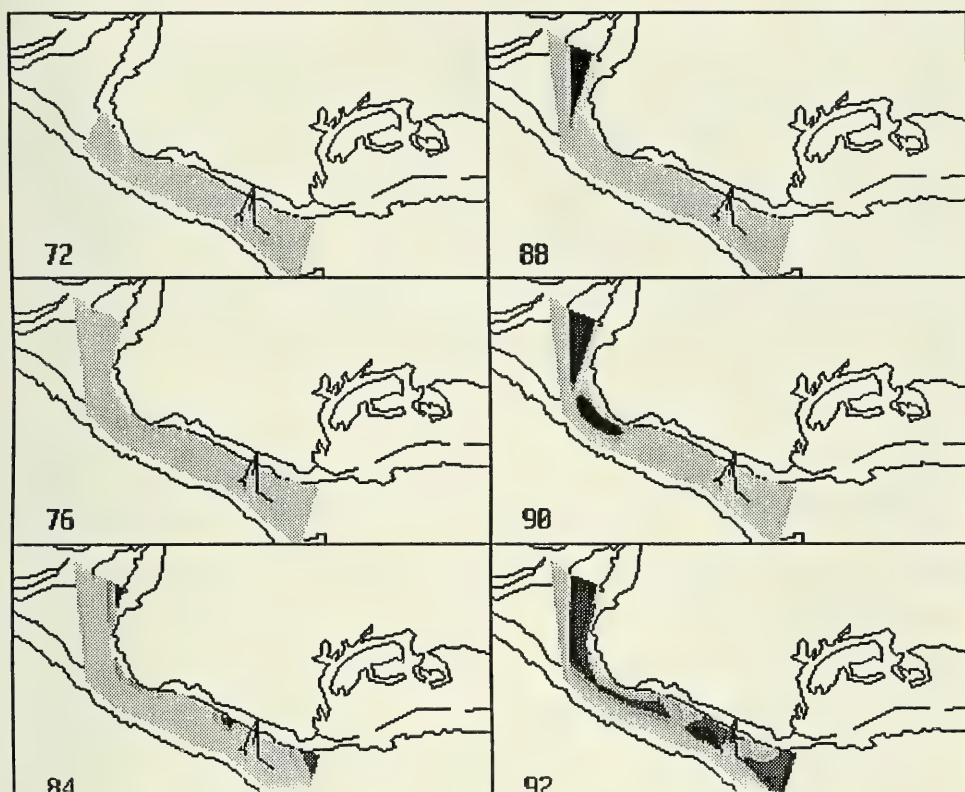


Fig. 4. *Amphiodia* spp. (no./0.1 sq. meter).

predicted due to the wide array of physical, biological and stochastic factors involved. To predict the time required to attain pre-disturbance levels is even more challenging. Within a given suite of physical parameter levels multiple stable species associations exist. Within the association of benthos the absence of a particular group of species is a natural variance and does not necessarily reflect an anthropogenic perturbation.

High species diversity and high abundance of ophiuroids may characterize shelf and slope depths. However, after mass mortalities from natural events (winter freeze, summer anoxia) ophiuroids are slow to return over even short distances to areas they had previously occupied. Even when physical habitat conditions are suitable, their life history patterns and the effects of biological inhibition or the lack of adult facilitation may still prevent or greatly slow the rate of resettlement.

Off Palos Verdes, the suite of ophiuroids was limited in both numbers of species and numbers of individuals in shelf and upper slope depths, and between the early 1950's and early 1970's ophiuroid populations were reduced to near zero levels. Since then, population levels have returned to the shelf in numbers of species and densities greater than found naturally along the 60 m isobath off the adjacent San Pedro shelf. The rate, pattern and magnitude of their return is consistent with literature data and the biology of ophiuroids. Under the current levels of outfall discharge, the progressive rate of resettling of ophiuroids to the central Palos Verdes shelf outside the ZID naturally continues.

Acknowledgements

We are pleased to dedicate this account to the memory of Dr. Thomas Scanland, colleague, friend and fellow traveler of the benthos. This paper was not presented in the Southern California Academy of Science Symposium on the Biology of Marine Wastewater Outfalls in Southern California conducted at California State University, Long Beach, on June 5, 1993, but was an account Dr. Scanland prepared for the Los Angeles County Sanitation District (LACSD) in 1987. We have tried to maintain the substance of his manuscript with help and updating provided by Dr. Doug Diener and Ms. Jan Stull. The latter provided recent information from the LACSD monitoring program. The editors of the proceedings are solely responsible for this version of Dr. Scanland's report.

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Synthesis, Issues, Trends and Recommendations

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Synthesis

Diener and Fuller describe the results of an eight year (1985-1993) monitoring program of a small (20 mgd), ocean outfall off Encina, California, which was modified from advanced primary treatment to full secondary treatment. Although their account focuses on the benthic portion of the study, some provocative and valuable insights emerged. Even though change to full secondary treatment produced significant improvements in DO, BOD, oil and grease and TSS in the effluent, these improvements were not detectable in the receiving waters. TOC concentrations normalized to % silt-clay were enhanced for gradient and ZID stations, however, conversion to full secondary treatment did not produce any significant change in sediment TOC concentrations near the outfall. For a variety of trace metals, only Cu normalized to % silt-clay was enhanced at the ZID stations, but enhancement was below concentrations for representative background levels.

In terms of benthic community structure there was no indication that full secondary treatment affected infaunal abundance, and diversity nearest the outfall was enhanced compared to the gradient and reference stations. In contrast, the brittle star *Amphiodia urtica* had depressed counts near the outfall. Since this pattern persisted even after 4½ years of full secondary treatment, the authors stated that depressed abundance of *A. urtica* near the outfall may not be related to discharge effects. Rather the authors suggested that increased predation associated with a reef-like structure provided by the outfall may contribute to extensive grazing pressure, resulting in low population levels of *A. urtica*. Perhaps the most significant biological event was associated with the winter storms and rains of late 1992 and January 1993, wherein there was a 25% reduction in community diversity.

Exclusive of reduced *A. urtica* populations which may be related to the outfall, but not the discharge, there was a lack of demonstrable, negative effects upon the infaunal community related to wastewater discharge. According to the authors, the waste water discharge is not degrading the environment and that a balanced indigenous population (BIP) is being maintained. For a small, well designed and well managed, coastal wastewater facility, conversion to full secondary treatment provided no significant improvements and may not be cost-effective for improving coastal water quality and minimizing biological impacts.

Stull describes results of two decades (1972 to 1992) of biological monitoring off Palos Verdes, California. Although the joint outfall system flow has increased commensurate with regional population growth from the forties, upstream reclamation, source control and a blend of advanced primary and partial secondary treatment have significantly decreased solids mass emission rates. According to

Stull the 1992 solids mass emission rate to the ocean was less than one-fifth that discharged in 1971. Reduction in solids mass emissions was accompanied by decreased trace contaminant discharges involving both organic and inorganic products.

In turn reduction in contaminants to the Palos Verdes shelf was also accompanied by dramatic improvements in many aspects of the biota. Soft-bottom benthos have repatriated to areas from which they were previously excluded. Increased numbers of species of arthropods and echinoderms, fewer molluscs, shared dominance among more species and decreased opportunists. Although other biological and meteorological events play important roles in controlling kelp populations, reductions in solids emissions contributed to this recovery. The distribution and diversity of epibenthic invertebrates from the Palos Verdes shelf has also increased since 1970, and these changes are attributed to widespread climatic events (1982–83 El Niño) and storms, together with improvements in habitat quality.

Fish populations also fluctuated over the two decades in response to large scale conditions (water temperature-El Niño). As conditions at the outfall changed, formerly enhanced species (Shiner perch, Curlfin sole, white seaperch, English sole, Dover sole) declined, and other species (California halibut, hornyhead turbot, California tonguefish) increased near the discharge. In addition to water temperature, changes in food resources (soft-bottom) benthos probably also contributed to the success of outfall related fishes. Fin erosion which was common in Dover sole in the early 1970s on the Palos Verdes shelf has disappeared, first at sites distant from the outfall, and later nearer the discharge.

However, one legacy of the conditions of the 1970s and earlier, still remains. The partly buried sediment reservoir of bioavailable DDT and PCBs, originally provided by the world's largest manufacturer of DDT from about 1950 to 1971, continues to pose health problems for both marine organisms and their human consumers. Local authorities closed the Palos Verdes commercial white croaker fishery in 1991, and there are advisories concerning sculpin, rockfishes and kelp bass not to be consumed at more than one meal every two weeks off White's Point.

Dorsey, *et al.*, describe the results of a monitoring program associated with the Hyperion outfall system emptying into Santa Monica Bay, California. The authors provide a brief, but informative description of the operation of the outfall system from 1894 to the present. A part of this description treats termination of the 7-mile digested sludge outfall in 1987, which sets the stage for assessing recovery time by benthic invertebrates. The authors benefited from an earlier benthic study (1952–1956), which predated operation of the 5-mile and 7-mile outfall.

Hyperion's infaunal monitoring program showed that total suspended solids (TSS) from the 5-mile outfall decreased markedly from 1984–85 through 1992–93. Even though there was some lag time between benthic response and decreased TSS, composition of infaunal communities around Hyperion's 5- and 7-mile outfall system has also changed markedly over the same period. The area of sea bottom with infaunal assemblages affected by the combined outfall system has reduced from $\cong 51 \text{ km}^2$ in 1987 to 16 km^2 at present. Based on the Pearson-Rosenberg Model, the authors characterized the respective assemblages from the 7-mile, digested sludge outfall (terminated in 1987) as shifting from degraded to

early transition, and the 5-mile outfall as shifting from polluted to late transitional to nearly normal.

The results from this study warrant serious consideration from students of marine pollution monitoring featuring wastewater outfalls because: (1) their work deals with a major ocean outfall ($\cong$ 320 mgd mixed primary and secondary effluent) on the Southern California Bight (SCB) which makes it one of the larger ones in the world; (2) presentation covers ten years (1983–1992) of continuous monitoring; (3) their account focuses on a prime topic (benthos) in marine pollution ecology; (4) the paper also describes a “natural experiment” via the recovery stage of benthos after termination of a digested sludge outfall (7-mile). With the huge expenditure of public monies for wastewater treatment facilities and mandated monitoring programs, it is encouraging to see that these marine scientists were able to document improved benthic conditions related to present engineering practices.

Gerlinger, *et al.*, report on a series of sediment bioassays germane to the County Sanitation Districts of Orange County’s ocean outfall. The bioassays serve to support a major field monitoring program by providing evidence to infer causal mechanisms under controlled conditions, and data for developing wastewater treatment guidelines.

Based on 925 specimens of the polychaetous annelid *Neanthes arenaceodentata* exposed for 20 days to sediment from seven monitoring stations including the outfall and preparations of artificial substratum (silica) and seawater from four collection periods in 1992 (April, July, September, October) Gerlinger, *et al.*, describe survival and growth (dry body weight). Survival was greater than 90% in nearly all treatments for all experiments. Under the above conditions sediment from near the outfall is not toxic to *N. arenaceodentata*. Although there are differences in growth across treatments (sediment from near the outfall commonly fostered higher daily growth rates) within an experiment, there are no significant differences in growth per sediment treatment or preparation. Even with the advantage of using a strain of polychaetes derived from a long-term, inbred, laboratory population to reduce genetic variability, some of the growth differences are not easily resolved.

These experiments are important for several reasons. They provide the first data on toxicity testing for the Districts’ outfall. Under the 20 day testing period, effects from toxicity are negligible. Moreover, these data provide guidelines for conducting more sophisticated testing involving the effect of sediments on reproduction and survival of offspring. In our opinion, reproduction deserves considerable attention in regards to natural populations or ones exposed to anthropogenic contaminants. Studies on reproduction and offspring survival are in progress. In addition, these sediment bioassays will provide data to contribute towards guidelines for the State of California’s pending monitoring and compliance regulations.

Perkins’ paper provides a sorely needed expertise in marine pollution ecology dealing with effects of wastewater discharge. Are the fish safe to eat? In this case Perkins focuses on the condition of recreational and commercial species of marine fish in terms of three types of lesions (neoplasms, putatively preneoplastic foci of cellular alteration, and severe hydropic vacuolation).

Based on 2,225 specimens distributed over three species (bigmouth sole—*Hypoglossina stomata*, hornyhead turbot—*Pleuronichthys verticalis*, white croaker—

Genyonemus lineatus), eight stations and six years (1986–1992), Perkins reports that the County Sanitation of Orange County's outfall station is most impacted (2.8% neoplasms), followed by the RIG site (2.4% neoplasms) near the ZID, and the inshore station at TO (1.8% neoplasms) near the mouth of the Santa Ana River. In view of the low percentage of incidence of neoplasms and slight differences among stations, the statistical, and more importantly ecological significance of these values remains uncertain. Perkins also confirms size/age-incidence (% lesion) risk relationships, and to a lesser degree gender related ones, reported by others elsewhere. As has been so often the case in the Southern California Bight, the white croaker again attracts attention. In this study the prevalence of severe hydropic vacuolation in liver cells was highest in the white croaker. Although the latter does not locally enjoy the same degree of infamy as off the Palos Verdes Peninsula, California, the white croaker deserves continued monitoring here. Perkins work also emphasizes how little we know about neoplasms in natural populations of marine fish, which makes assessment of such features in populations exposed to anthropogenic contaminants even more challenging.

Pitman's paper also addresses a fundamental question related to the effect of open ocean waste water discharge. Are the shellfish safe to eat? In this study he focuses on bacterial concentrations in seawater and mussels and oysters along the coast of Goleta-Santa Barbara, California. Specifically his study deals with bacterial concentrations in wastewater discharges of the Goleta Sanitary District (GSD), the City of Santa Barbara Wastewater Treatment Plant, several stormwater sites, and shellfish in cages associated with shellfish mariculture.

Based on his work Pitman showed that bacteria levels in the ocean water are consistently low or undetectable in the shellfish mariculture area, except during periods of terrestrial runoff due to rainfall. The water column at the mariculture site consistently met strict standards for approved growing water. However, bacteria in shellfish meat tissue sometimes exceeded the standard for human consumption. Highest percent of samples exceeding shellfish standards occurred near the center of the study area, and not near GSD and the City of Santa Barbara. Tissue bacteria levels were affected by Goleta slough and non-point source runoff. Finally, stormwater runoff samples typically contained tens of thousands of coliform bacteria.

Pitman's study emphasizes the need to carefully consider dominant physical oceanographic processes, major point contamination sources, and potential non-point contaminant sources prior to siting a safe and viable mariculture project. Although it is not possible to always accommodate all these processes and events; early, serious consideration of these issues can go a long way to provide condition to ensure shellfish safe to eat.

Scanland's review (this proceedings) focuses on the concept of succession as it relates to recruitment in soft-bottom marine habitats and the role of ophiuroids in this process. His choice of ophiuroids was both pertinent and opportune. Ophiuroids are considered as bioindicators of wastewater discharge by some marine ecologists working in the Southern California Bight (SCB) and the brittlestar *Amphiodia urtica* Lyman is presently the subject of extensive field and laboratory studies by several regional organizations.

Scanland reminds us that succession is a highly complex process. According to him species composition, number of species, and abundance of assemblages from

a previously disturbed area cannot be accurately predicted due to the wide array of physical, biological and stochastic factors involved. To predict the time required to attain pre-disturbance levels is even more challenging. Even when physical habitat conditions are suitable, ophiuroid life history patterns and the effects of biological inhibition or the lack of adult facilitation may still prevent or greatly slow the rate of resettlement.

While Scanland noted that abundance and diversity of ophiuroid species were reduced to near zero levels between the early 1950's and late 1970's off Palos Verdes, California, particularly near ocean outfalls; he also recorded enhanced abundance and diversity following this period, and extending through the present. In 1987 he correctly predicted that *Amphiodia urtica* would progressively reoccupy areas in the SCB formerly vacated. His review also serves to caution against undue reliance on a single bioindicator species because of the vagaries of succession and without extensive and thorough knowledge of the life history of the target species.

Issues

Based on this proceedings, a number of issues associated with ocean outfalls emerged. Many issues are common to marine scientists studying the effects of ocean outfalls elsewhere whereas a few issues represent local or regional processes and concerns. The former includes the volume and rate of emission flows, level of treatment, importance of oceanographic circulation, effect of natural processes, value of long term monitoring, pre operation and post operation studies, public health concerns and multiple non-point sources of pollution. These are significant issues commonly represented and extensively treated in a variety of journals, symposia and books. In addition, other issues that may be more germane to southern California, include the partly buried reservoir of DDTs and PCBs off the Palos Verdes Shelf, interest in coastal mariculture (certainly not unique to southern California) and watershed management (an emerging national need).

The cumulative rate of flow of the four major dischargers (City of San Diego, Orange County, County of Los Angeles, City of Los Angeles) of wastewater effluent into the coastal waters of southern California is approximately 1100 mgd. (1 mgd. = 3.785×10^6 l). This volume of effluent certainly deserves attention, if not respect. Moreover, this volume projects these dischargers among world class practitioners of wastewater disposal. A partial response to this volume of effluent is represented by the symposium and present proceedings as each participant represents public monies associated with discrete sanitation districts and their respective monitoring programs. For example, the County Sanitation Districts of Orange County, California, has expended \$19 million from 1985–1994 on its ocean monitoring program. The work of Gerlinger, *et al.*, and Perkins represent just a small portion of this effort. Other sanitation districts (San Diego, LA County, City of LA) annually spend \$1 million or more each on their monitoring program, and they have been conducting their studies longer than CSDOC. In addition, the Environmental Protection Agency, National Oceanic and Atmospheric Administration, the Southern California Coastal Research Project, the U.S. Army Corps of Engineers, the Mineral Management Services and independent investigators have regularly monitored environmental conditions in coastal waters of southern California. Accordingly, it can be confidently stated that there has been

a major federal and regional organizational response to study the effects of the major volume of effluent discharged into California's coastal waters.

Related to the volume of discharge is the level of treatment the effluent receives. It has long been a premise among sanitation engineers and marine scientists that deep water ocean outfalls off the coast of southern California, are a more viable solution to wastewater disposal than on the east coast and gulf coast of the United States. This premise is based on significant differences in geology between the two coasts. The east coast resides on the trailing edge of the North American plate, presently providing a broad, shallow, gently inclining shelf. In contrast, the west coast represents the leading edge of the North American plate providing a very narrow, steep, rapidly sloping shelf. As a result, deep ocean outfalls are generally more economically feasible on the west coast than the east and Gulf coasts.

Assuming operation of a deep water ocean outfall the level of wastewater treatment can vary with the particular oceanographic conditions. Dorsey, *et al.*, and Stull (this proceedings) show how a combination of upstream reclamation, increased source control and either combined advanced primary and partial secondary treatment (Palos Verdes) or full secondary treatment (under construction at Hyperion-Santa Monica Bay), have significantly improved the quality of environmental conditions on the shelf. In the case of Palos Verdes, significant improvements in the status of kelp populations, soft-bottom benthos, epibenthic invertebrates and finfish have occurred. Similar improvements in soft-bottom benthos were associated with remission of the 7-mile sludge outfall and partial secondary treatment (50:50) off Huntington Beach, together with increased source control has also resulted in improved bottom conditions (Orange County Districts—Annual Reports).

Diener and Fuller (this proceedings) show that full secondary treatment significantly improved bottom conditions off a small outfall near Encina, but that there were no indications of temporal changes in soft-bottom benthos (except for *A. urtica*) related to improved treatment levels. The same authors suggest that in this case full secondary treatment may not be cost-effective, and for that reason is unwarranted. Their position supports the wisdom of assessing the necessary level of treatment rather than applying universal full secondary treatment to all ocean outfalls. Depending on physical and geological oceanography, outfall design and operation, volume and history of effluent flow, effluent quality and associated watershed conditions, some outfalls simply will not require full secondary treatment to maintain acceptable levels of water quality. Under some conditions conversion to full secondary treatment may represent an unnecessary burden to taxpayers, the savings which could be more judiciously reallocated to improved source control, watershed management and abatement of multiple nonpoint sources of contaminants.

Another issue associated with ocean monitoring which deserves emphasizing involves physical oceanography or oceanographic circulation. Pitman's study (this proceedings) focuses on; are the shellfish safe to eat? To answer this question, his study demonstrates the importance of knowing the dominant regional and local oceanography as it relates to transport of bacteria enhanced by wastewater effluent or shoreline drainage. Detailed studies of physical oceanography are very necessary to predict the fate and direction of contaminant dispersal, particularly in regards to sedentary, suspension feeders, featured in mariculture. Knowledge of local

oceanography is also very necessary to establish sampling programs, locating reference stations, transitional stations and of course, test stations. Serious attention should be given to local circulation patterns to avoid unnecessary sampling in inappropriate or poorly sited stations.

Another aspect of field monitoring, which is generally appreciated by practitioners, but commonly loses currency when transmitted to a concerned lay public involves the effect of the interaction between natural events or processes and anthropogenic activities. Diener and Fuller, Dorsey, *et al.*, and Stull underline the importance of natural processes influencing interpretations of the effects of ocean outfalls. For their study Diener and Fuller, report on the effect of winter storms and an above average rainfall in late 1992 and January 1993, producing as much as 25% variability in benthic diversity. A 25% reduction in diversity without an apparent or conspicuous natural process might readily and mistakenly be attributed to anthropogenic activities associated with wastewater discharge. It is imperative that the range of natural variability be determined as fully as possible for a study area off an ocean outfall prior to attributing negative effects of the latter on benthic populations. Failure to do so may exaggerate effects of wastewater discharge, seriously prejudicing management decisions.

Winter sandstorms play havoc with kelp beds, but provide considerable energy for sediment transport, enhancing dispersal and dissemination of surface contaminants. El Niño's bring warm water masses to an area, temporarily fostering emigration of cooler water species of fish and immigration of warmer water or shallow dwelling species. Taken alone or out of context with natural processes the deterioration or destruction of kelp beds might be solely attributed to contaminants or increased turbidity from an outfall. The movement of finfish into and out of an outfall area might be construed as the flux of pollution sensitive and pollution tolerant species, without recourse to significant water change associated with El Niños. Marine scientists must continue to document these natural processes in monitoring studies to avoid misinterpretations by a concerned lay public.

Long-term monitoring is another important concern among marine scientists. It is the rare scientist who does not seek additional replicates, of an expanding network of stations, over an ever increasing period of time. The almighty N is never big enough. In all fairness to this concern, marine scientists are all too aware of how natural events contribute to variability in annual and seasonal patterns. Without benefit of long-term studies it is very difficult to determine whether conditions associated with human activities may be deteriorating or improving. Diener and Fuller report on eight years of data (this proceedings), Dorsey, *et al.*, on ten years of benthic monitoring, and Stull on twenty years of monitoring an ocean outfall. These long-term studies are extremely important chronicling biotic and abiotic variables in coastal waters of southern California. Although these and other monitoring studies (San Diego, Orange County) are required by law, in addition to addressing specific questions about outfall impacts, they also represent an unusually large and relatively unique set of long-term measurements. Federal and state funding agencies do not have the mandate, and almost as importantly the resources, to support long-term (decades) studies, even if they want to. As a result, ocean monitoring by regional sanitation districts throughout the United States represent a legal responsibility to address applied environmental problems,

and coincidentally provide an unrivaled opportunity to conduct long-term research on basic problems in ecology. The wealth of information acquired by large, well funded, monitoring programs, subject to stringent quality assurance/quality control protocols which might embarrass many scientists, because of their shortcomings, should not be casually dismissed. Long-term ocean monitoring programs conducted by major discharges in southern California should be considered an important national resource.

Inherent in monitoring programs local and world wide are pre operation and post operation phases. Simply stated, what was the status of the respective habitat before the anthropogenic activity began, and what was the environmental response to termination of that activity? Unfortunately, marine ecologists do not always realize satisfactory answers to these questions. Too many years may have passed between the pre operation study and the initiation of an engineering project. Perhaps no baseline studies were performed. Selection of reference and transition stations may have been ill advised. At the other end of the spectrum perhaps no post operation studies were performed or at best the study covered only one year.

Dorsey, *et al.*, (this proceedings) participated in a study where a number of important ingredients for monitoring were met. First, a major study was conducted from 1953–54 in Santa Monica Bay, for the purpose of siting two (5-mile and 7-mile) outfalls. During operation of the outfalls semiannual monitoring was conducted at test stations (in and around the outfall) and reference stations for several decades. In 1987 sludge disposal from the 7-mile outfall was terminated providing the opportunity for a post operation or recovery phase experiment of a major ocean outfall. The semi annual sampling continues, and has documented important changes as benthic conditions improve with associated improvements of marine biota. This important pre operation–post operation experiment was only possible because of the mandated requirements associated with long-term monitoring of an ocean outfall.

Of major importance to anyone spending time with the ocean, is the water safe (bacterial levels) to swim in, and are the fish and shellfish safe (contaminants, parasites, disease) to eat? Regardless of the level of treatment or prevailing oceanographic circulation, wastewater discharge from an ocean outfall intuitively poses a serious health risk to the public. Cholera, ciguatera, domoic acid and paralytic shellfish poisoning are related to consumption of seafood. Among these, only cholera is directly linked to consumption of seafood containing bacterial contamination. The potential for expanded development of mariculture along California's 1,000 mile plus coastline has not been realized for a variety of reasons including concerns about acceptable levels of bacteria in the water column. Until the conditions (anthropogenic and natural) governing bacterial contamination for any given area are resolved, that area remains suspect as a candidate for mariculture. Pitman (this proceedings) focuses on levels of bacterial consumption by shellfish and how these levels are influenced by oceanographic circulation, watershed processes, and levels of wastewater treatment (discussed above). Related to the topic of safely eating seafood, Perkins (this proceedings) describes in detail the histopathology of several important species of demersal fish and the level of incidence of parasites and neoplasms as measures of stressful response to contaminants from the outfall. Their concerns and studies are germane to other workers interested

in siting and operating mariculture ventures and pursuing conventional fisheries elsewhere.

A topic rapidly gaining stature in monitoring studies nationwide is multiple non-point sources of pollution. Although all the participants in the symposium are acutely aware how storm drains, river runoff, oil seeps, and atmospheric fallout contribute to contaminant loads in coastal waters, Diener and Fuller and Pitman (this proceedings) actually describe conditions related to non point sources and how these multiple sources affected biotic variables (benthic populations and bacterial levels). The identification of multiple non point sources does not minimize the contribution of contaminants to the ocean by outfalls or diminish the responsibilities of the dischargers rather it permits for a more accurate accounting of total contributions to the ocean. Moreover, under certain conditions (heavy rainfall) contributions from non point sources can exceed those of ocean outfalls by several orders of magnitude for brief periods of time. Once an accurate budget of major non point sources has been established, conditions influencing these sources can be assessed and hopefully mitigated. However, recognition of the importance of non point sources to coastal waters has important ramifications influencing human activities elsewhere (watershed).

One outfall issue which may be unique to southern California, but certainly merits recognition elsewhere, involves the partly buried reservoir of DDT and PCB off Palos Verdes. Stull (this proceedings) informs us that residues from the manufacture of DDT were incorporated in the effluent of the Los Angeles County outfall from 1950 to about 1971. Depending on the authority or source, estimates of the volume of DDT vary greatly, but perhaps several thousand metric tons may have been discharged over the 21 year period. Even though this discharge was disconnected from the sewer line in 1971, the volume of material coupled with its slow rate of degradation still serves as a cause celebre in southern California's coastal waters. Although conventional wisdom about the buried DDT being the single most important source of contaminants in southern California may have become dogma, it is difficult to refute heavy and continuing bioaccumulation of DDT and PCB by particular species of fish off Palos Verdes. This relationship is particularly marked with negligible amounts of DDT and PCB discharged from the outfall under present conditions. Stull does us a favor by reminding us of this situation.

Trends

Although the papers in this proceedings represent only a portion of the extensive monitoring effort in southern California's coastal waters, they do provide enough evidence to briefly describe a few major trends for this area. First, Dorsey, *et al.*, and Stull present data showing significant reduction of solid emissions to the shelf. Annual reports (not included herein) prepared by the City of San Diego and Orange County and the paper by Diener and Fuller on a smaller outfall off Encina show exactly the same trend. Second, concentrations of organic and inorganic contaminants in sediments in and around these outfalls have significantly decreased over the past 10–20 years. Third, the reduction of sediment contaminants is inversely related to improved bottom conditions. Areas formerly characterized as containing high concentrations of contaminants, high levels of sulfides and BOD, have become much smaller in size, as "ring around the outfall" has greatly diminished.

Fourth, there is also an inverse relationship between reduced sediment contaminants and increased benthic community structure as measured by increasing number of species and migration of species closer to the outfalls formerly vacated during earlier more stressful conditions. Fifth, in the paper featuring histopathology Perkins shows that the Orange County outfall is not a center or source of epizootic conditions for parasites and neoplasms of several species of demersal fish. Sixth, increased efforts at upstream reclamation, stronger commitment to and enforcement of source control protocols, and wastewater treatment ranging from advanced primary-partial secondary (50:50) to full secondary treatment, have transpired in the southern California coastal zone in the last 20 years. These practices represent a major trend contributing to improved ocean conditions. The question of the economic benefit of full secondary treatment remains unresolved. Only Encina has achieved this status with apparently little significant ecological impact. At larger outfalls source control and solids reductions may obscure the benefits resulting from secondary treatment.

Recommendations

Although the total spectrum of research and development efforts on pollution in southern California's coastal waters is not covered here, this proceedings has identified a number of issues upon which to suggest recommendations for future studies, protocols and considerations. For example, those papers describing soft-bottom benthos (Diener and Fuller, Dorsey, *et al.*, Stull) all owe allegiance to solid taxonomic practices. In southern California solid taxonomy has been espoused and provided by the southern California Association of Marine Invertebrate Taxonomists (SCAMIT). SCAMIT consists of a group of people from a wide variety of organizations (sanitation districts, consulting firms, public agencies, academia) who are active taxonomic practitioners with marine invertebrates. This group meets monthly, shares specimens, conducts identification exercises, exchanges taxonomic literature, prepares taxonomic notes, and sponsors identification clinics by specialists. A prime codicil or concern of SCAMIT is standardization of taxonomic usage. Is species A of one worker species D of another? Monthly meetings address these problems, and differences in taxonomic usage are resolved. In view of the extensive amount of monitoring conducted throughout southern California, SCAMIT provides a major service towards standardization. SCAMIT's activities have also served as an impetus to generate another group dedicated to standardization of chemical analyses of sediment and water column. These activities satisfy an important need for quality control of monitoring activities in southern California.

With four large sanitation districts, numerous consulting firms, various agencies (NOAA, EPA, Corps of Engineers, SCCWRP) all involved in monitoring studies, the need for standardization for almost all aspects of monitoring is necessary to provide the basis for comparison of results across studies. This need has been recognized by many for a long time and we use this occasion to sing to the chorus. Moreover, what is encouraging, after years and years of hand wringing and chest beating, a strong effort has been made to bring these various parties together under a single operating rubric. With the cooperation of many agencies and under the sponsorship of EPA the Southern California Bight Pilot Project (SCBPP) was developed. SCBPP is an integrated, coordinated regional environmental moni-

toring program. The program attempts to standardize the sampling design, collection methods, sample processing laboratory protocol, and database management through a standardized quality assurance-quality control process.

SCBPP conducted its initial cruise in the summer of 1994. This was the first instance for regional monitoring where several ships measured the same variables, at the same time with the same equipment which had been intercalibrated, and organisms were sampled with the same collecting gear and samples were similarly processed. This level of regional coordination has been a long time coming, and we strongly support its participants and recommend a long and vigorous commitment to this approach.

Assuming that a foundation for a regional monitoring program is in place, we urge consideration of an addendum to this agenda. Long-term monitoring (Diener and Fuller, Dorsey, *et al.*, Stull) has clearly demonstrated that measures of benthic community structure can be successfully used to detect and understand significant ecological changes in southern California's ocean waters. Similar results have been recorded earlier by many other workers all over the world. We have no argument with some of the conventional monitoring tools used regionally and worldwide. However, it is our opinion that for some of the permits in southern California some monitoring requirements are unnecessary and ineffective, and for that reason waste considerable sums of taxpayers money. Large programs represented by sanitation districts are required by law to sample over 100 priority pollutants. Years and years of sampling (Dorsey, *et al.* and Stull) have showed that many of these pollutants occur below detection limits or that there have been little or no changes for 10 or 20 years. Without digressing into a discussion about the advisability of lowering detection limits, which really awaits improvements and refinements in analytical chemistry, we strongly recommend that monitoring programs embrace a more flexible, hypothesis based approach. The hundreds of thousands of measurements of nondetectible pollutants adds greatly to the cost of these expensive programs, and adds very little to our understanding of causal mechanisms. Funding for these measures should be reallocated to assessing functional aspects of communities exposed to ocean outfalls. In addition to conventional monitoring protocols to keep track of long-term trends, the monitoring protocol should focus on secondary production of benthos and finfish, predator-prey relationships, energy flow, bioaccumulation, parasites and disease. To some extent efforts along these lines have been pursued (Gerlinger, *et al.*, and Perkins), but these are exceptions rather than frequently applied protocols. The southern California monitoring community has successfully documented seasonal and annual trends of biotic and abiotic variables to the point where these only need regular and modest attention. It is long overdue for incorporation of hypothesis testing of causal mechanisms into regular monitoring protocols. Hypotheses should focus on functional relationships that are most relevant to a region or particular outfall. This approach should also emphasize field and laboratory experiments. We do not want to recreate the wheel here (sediment quality triad, microcosms), but we advocate experimentation to be incorporated into regional monitoring. Gerlinger, *et al.*, is a positive move in this direction, but we envision a more expanded effort including field experiments. Physiological techniques and cellular and molecular approaches have been used to advantage by European researchers and they should be tested and adopted when relevant and feasible. Thus, we

recommend that regional monitoring consist of a blend of conventional monitoring technique to provide long-term records and standardization, coupled with a flexible hypothesis testing mode to focus on causal mechanisms, taking advantage of opportunities (El Niño, winter storms, fluvial runoff) as a part of the program.

The need or desire to incorporate a flexible, hypothesis testing mode under a regional monitoring program prompts another recommendation. Pitman describes the contribution of contaminants to the shelf from multiple nonpoint sources and both Pitman and Diener and Fuller allude to the effects of terrestrial runoff associated with heavy rainfall. A ground swell is gathering that the decline of coastal fisheries in the United States and abroad is not just associated with over fishing and pollution, but may be strongly influenced by diversion of fresh water. One of the editors (I. Haydock) and a co-worker at the Orange County Districts (Dr. Michael Rozengurt) have analyzed freshwater flow to bays, estuaries and coastal zones in the United States and around the world. Rozengurt has established quantitative relationships between water diversion (minimum of 25-30% of spring flow) and diminished fisheries production for San Francisco Bay, Chesapeake Bay, Caspian Sea, Black Sea and the Sea of Azov. His seminal work is now supported by the experience of other hydrologists and biologists throughout the world. With this brief background it is our contention that regional ocean monitoring is myopic, if it does not consider the effects of local freshwater runoff on ocean communities. Salt water intrusion, reduced nutrient loads, protracted or shortened salinity imbalances are all factors related to freshwater diversion that are known to affect fish populations in bays, estuaries and coastal zones. Although watershed management as it impacts the coastal zone has generated its own symposia, at this time we simply want to raise the level of awareness of the importance of this topic to administrators and recommend that regional monitoring for southern California, and for that matter elsewhere in the United States, adopt watershed management in their protocols in order to fully assess the natural link between land and sea.

SCHEDULE OF PRESENTATIONS

Special Symposium Sponsored by the
Southern California Academy of Sciences

“The Biology of Marine Wastewater Outfalls in Southern California”

California State University Long Beach
Long Beach, California

June 5, 1993 0800–1200 hours

- Convenor: Dr. Don Maurer, Biology Department, CSULB
- Panel Moderator: Dr. Irwin Haydock, Manager, Compliance Division County Sanitation Districts of Orange County, California
- 0800–0805 Introduction: Don Maurer
- 0805–0825 The Influence of *Myriochele* sp. M (Polychaeta: Oweniidae) on the Community Structure of the Benthos near the Point Loma Wastewater Outfall.
Ron G. Velarde, Metro Wastewater Division, City of San Diego, CA.
- 0825–0845 Infaunal Patterns in the Vicinity of a Small Coastal Wastewater Outfall and the Lack of Community Change to Secondary Treatment.
Dr. R. Douglas Diener, MEC Analytical Systems, Inc., Carlsbad, CA.
- 0845–0905 Two Decades of Marine Biological Monitoring, Palos Verdes, California.
Ms. Jan Stull, Senior Scientist, Los Angeles County Sanitation Districts, Whittier, CA.
- 0905–0925 Changes in Assemblages of Benthic Organisms Around Sewage Outfalls in Santa Monica Bay, California.
Dr. J. H. Dorsey, M. Dojiri, C. A. Phillips, J. D. Roney and G. Deets. Environmental Monitoring Division, Hyperion Treatment Plant, Playa del Rey, CA.
- 0925–0945 *Coffee Break*
- 0945–1005 Differences in the Biology of the Ophiuroid *Amphiobia urtica* near Sewage Outfalls of Southern California.
Dr. B. Thompson,¹ D. Tsukada² and A. Jirik.² ¹Aquatic Habitat Institute, Richmond, CA. and ²Southern California Coastal Water Research Project, Bolsa Chica, CA.
- 1005–1025 *Neanthes*' Survival and Growth: Test of Sediment Quality Near an Orange County Sewage Outfall. T. V. Gerlinger,¹ M. Budris,¹ and Dr. D. J. Reish.² ¹County Sanitation Districts of Orange County, Fountain Valley, CA., and ²California State University, Long Beach, CA.
- 1025–1045 Wastewater Bacteria and Shellfish.
Ron Pitman, Brown & Caldwell, Irvine, CA.
- 1045–1105 An Overview of Hepatic Neoplasms, Putatively Preneoplastic Lesions and Associated Conditions in Fish Sampled During the County Sanitation Districts of Orange County's 1988–1992, 301(h) Ocean Monitoring Program.

Dr. E. M. Perkins, Department of Biological Sciences, University of Southern California, Los Angeles, CA.

1105-1200

Panel Discussion: Dr. Irwin Haydock and Participants.



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INSTRUCTIONS FOR AUTHORS

The BULLETIN is published three times each year (April, August, and December) and includes articles in English in any field of science with an **emphasis on the southern California area**. Manuscripts submitted for publication should contain results of original research, embrace sound principles of scientific investigation, and present data in a clear and concise manner. The current AIBS *Style Manual for Biological Journals* is recommended as a guide for contributors. Consult also recent issues of the BULLETIN.

MANUSCRIPT PREPARATION

The author should submit *at least two additional copies with the original*, on $8\frac{1}{2} \times 11$ opaque, nonerasable paper, double spacing the entire manuscript. **Do not break words at right-hand margin anywhere in the manuscript.** Footnotes should be avoided. **Manuscripts which do not conform to the style of the BULLETIN will be returned to the author.**

An abstract summarizing in concise terms the methods, findings, and implications discussed in the paper *must* accompany a *feature article*. *Abstract should not exceed 100 words.*

A **feature article** comprises approximately five to thirty typewritten pages. Papers should usually be divided into the following sections: abstract, introduction, methods, results, discussion and conclusions, acknowledgments, literature cited, tables, figure legend page, and figures. Avoid using more than two levels of subheadings.

A **research note** is usually one to six typewritten pages and rarely utilizes subheadings. Consult a recent issue of the BULLETIN for the format of *notes*. Abstracts are not used for notes.

Abbreviations: Use of abbreviations and symbols can be determined by inspection of a recent issue of the BULLETIN. **Omit periods after standard abbreviations:** 1.2 mm, 2 km, 30 cm, but Figs. 1–2. Use numerals *before* units of measurements: 5 ml, but nine spines (10 or numbers above, such as 13 spines). The metric system of weights and measurements should be used wherever possible.

Taxonomic procedures: Authors are advised to adhere to the taxonomic procedures as outlined in the International Code of Botanical Nomenclature (Lawjouw et al. 1956), the International Code of Nomenclature of Bacteria and Viruses (Buchanan et al. 1958), and the International Code of Zoological Nomenclature (Ride et al. 1985). Special attention should be given to the description of new taxa, designation of holotype, etc. Reference to new taxa in titles and abstracts should be avoided.

The literature cited: Entries for books and articles should take these forms.

McWilliams, K. L. 1970. Insect mimicry. Academic Press, vii + 326 pp.

Holmes, T. Jr., and S. Speak. 1971. Reproductive biology of *Myotis lucifugus*. J. Mamm., 54:452–458.

Brattstrom, B. H. 1969. The Condor in California. Pp. 369–382 in *Vertebrates of California*. (S. E. Payne, ed.), Univ. California Press, xii + 635 pp.

Tables should not repeat data in figures (line drawings, graphs, or black and white photographs) or contained in the text. The author must provide numbers and short legends for tables and figures and place reference to each of them in the text. Each table with legend must be on a separate sheet of paper. All figure legends should be placed together on a separate sheet. **Illustrations and lettering thereon should be of sufficient size and clarity to permit reduction to standard page size;** ordinarily they should not exceed $8\frac{1}{2}$ by 11 inches in size and after final reduction lettering must equal or exceed the size of the typeset. All half-tone illustrations will have light screen (grey) backgrounds. Special handling such as dropout half-tones, special screens, etc., must be requested by and will be charged to authors. **As changes may be required after review, the authors should retain the original figures in their files until acceptance of the manuscript for publication.**

Assemble the manuscript as follows: cover page (with title, authors' names and addresses), abstract, introduction, methods, results, discussion, acknowledgements, literature cited, appendices, tables, figure legends, and figures.

A **cover illustration** pertaining to an article in the issue or one of general scientific interest will be printed on the cover of each issue. Such illustrations along with a brief caption should be sent to the Editor for review.

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COVER: White Sea Anemone (*Metridium giganteum*) on the Orange County Sanitation District Ocean Outfall. Location: 5 miles off the mouth of the Santa Ana River at a depth of 60 meters, Orange Co., Ca. Photographed by Don Siverts of Undersea Graphics Inc.